**SECRET**

MOD Form 45B

PRO

# MINISTRY OF DEFENCE

1. ATTENTION IS DRAWN TO THE NOTES ON THE INSIDE FLAP
2. ENTER NOTES OF RELATED FILES ON PAGE 2 OF THIS JACKET

DIVISION

D. Sc. 6.

FOR REGISTRY USE ONLY

18 Sept 00 (o)

Registered file number

D/407/104/11/10

Date opened 17/8/70

SUBJECT

NUCLEAR WEAPON EFFECTS — SYMPOSIUM - DECEMBER 1970.

| Referred to | DATE | Referred to | DATE | Referred to | DATE | Referred to | DATE |
|---|---|---|---|---|---|---|---|

DEFE 7/2401

CLOSED 10-3-76.

DISPOSAL or PA Action

See note on file flap

SR 1999

DOWNGRADING

(to be completed when the file goes out of current use)

(i) This file may be downgraded to:—

* CONFIDENTIAL
* RESTRICTED
* UNCLASSIFIED
on (Insert DATE)........................
OR

(ii) Return for Review
on (Insert DATE)........................

........................................
CERTIFYING OFFICER

........................................
APPOINTMENT AND BRANCH

........................................
DATE

**SECRET**

HPW 858861 33M 9/71

MINISTRY OF DEFENCE
D. Sc 3
16 MAR 1972
FILE 104/11/10.

CONFIDENTIAL

104/11/10

DSc6
WNS

Ref: SSWL/203
19 November 1971

E44/1

## Text for talk on "Results of Studying Survivability at AWRE" to be given at RARDE Symposium

J D DAVIES, AWRE ALDERMASTON

## 1 INTRODUCTION

A little over 2 years ago the Director AWRE agreed to provide effort to undertake the task of assessing the vulnerability of service equipment nominated by the Weapon Effects Study Group under the Chairmanship of Dr F H Panton. During the next 10 minutes I will summarise the highlights of the results of these studies with particular emphasis on those aspects which are generally applicable to the problem of achieving survivability of electronic equipment in a nuclear environment.

## 2 PROGRAMME

The programme undertaken at AWRE is given in Fig 1 and the ticks indicate the weapon effects studied, ie the Field Artillery Computer Equipment (FACE) was studied in terms of its response to nuclear radiation (neutrons and gammas) and the electromagnetic pulse. With the exception of the EMP assessment of the Bruin system and the neutron and gamma assessment of the PRC 350 all the listed activities have been completed and in the majority of cases reports have been issued.

## 3 RESULTS

To discuss the detailed results of these assessments would (a) require a lot more time than is available and also (b) require a detailed knowledge of the designs and functioning of the equipment. I therefore propose to pick out general results of the responses of equipment that are applicable to and I hope can be eliminated in future designs of equipments.

WNS Seen

Loa.

CONFIDENTIAL

## 3.1 Blast

The first significant result is the vulnerability of aerial systems to blast. The studies of the Clansman ground station aerials, masts and elevated aerials, Bruin aerial systems and the ZB 298 radar dish and aerial clearly indicate the susceptibility of aerial systems. Guys snap, pickets are pulled out of the ground and the aerials topple on application of the blast force.

The next significant result is the vulnerability of wheeled vehicles. The studies of the C45 VHF set mounted in a landrover, and the Bruin equipment housed in 'B' vehicles comprising 1 and 3 ton trucks and transportable carriers vehicle mounted, confirmed the vulnerability of wheeled vehicles to blast. The landrover in the side-on orientation overturns several times and slides several tens of feet. This is also the fate of the 'B' vehicles. This overturning and sliding causes damage to attached whip aerials, severs power connections with a resulting fire hazard, and imposes a severe mechanical environment on the internal equipment with a high probability of severe damage.

Fig 2 is a plot of the damage radii against yield for these blast effects. Curve 4 is moderate damage to aerials, curve 3 moderate damage to wheeled vehicles, curve 2 moderate damage to tracked vehicles and curve 1 the 3000 rad curve. At various yields I have indicated the ratio of the vulnerability shadow area for that particular effect compared with the 3000 rad area. For example at a yield of 100 kT the vulnerability shadow area of a communication system is 10.8 times the shadow area corresponding to 3000 rad. The curves also show the reduction in the shadow area of tracked vehicles.

## 3.2 Radiation

Although the studies have shown that neutrons do cause trouble primarily in power circuits, careful choice of components can eliminate these problems, but the gamma effects are more significant. You have already heard of the effects of the gamma pulse on FACE; the studies on BID 150 and BID 200 have shown that several circuits are affected by the gamma pulse at rates as low as 1 x $10^6$ rads/sec. In the latter cases the disturbance does not however cause an operational failure, as the system viability is not affected by transient perturbations. Nevertheless perturbations at $10^6$ r/sec level do occur and digital systems, particularly those involving storage systems will be in trouble.

Fig 3 is a repeat of Fig 2 but with the additional curve showing the $10^6$ rads/sec level and Fig 5 has the added data of relative shadow areas. Fig 4 shows yield and distance relationships for various gamma dose rates.

Figs 5 and 6 illustrate the relative shadow areas for $10^6$ rads/sec and 3000 rad at yields of 50 kT and 200 kT respectively.

## 4 SUMMARY

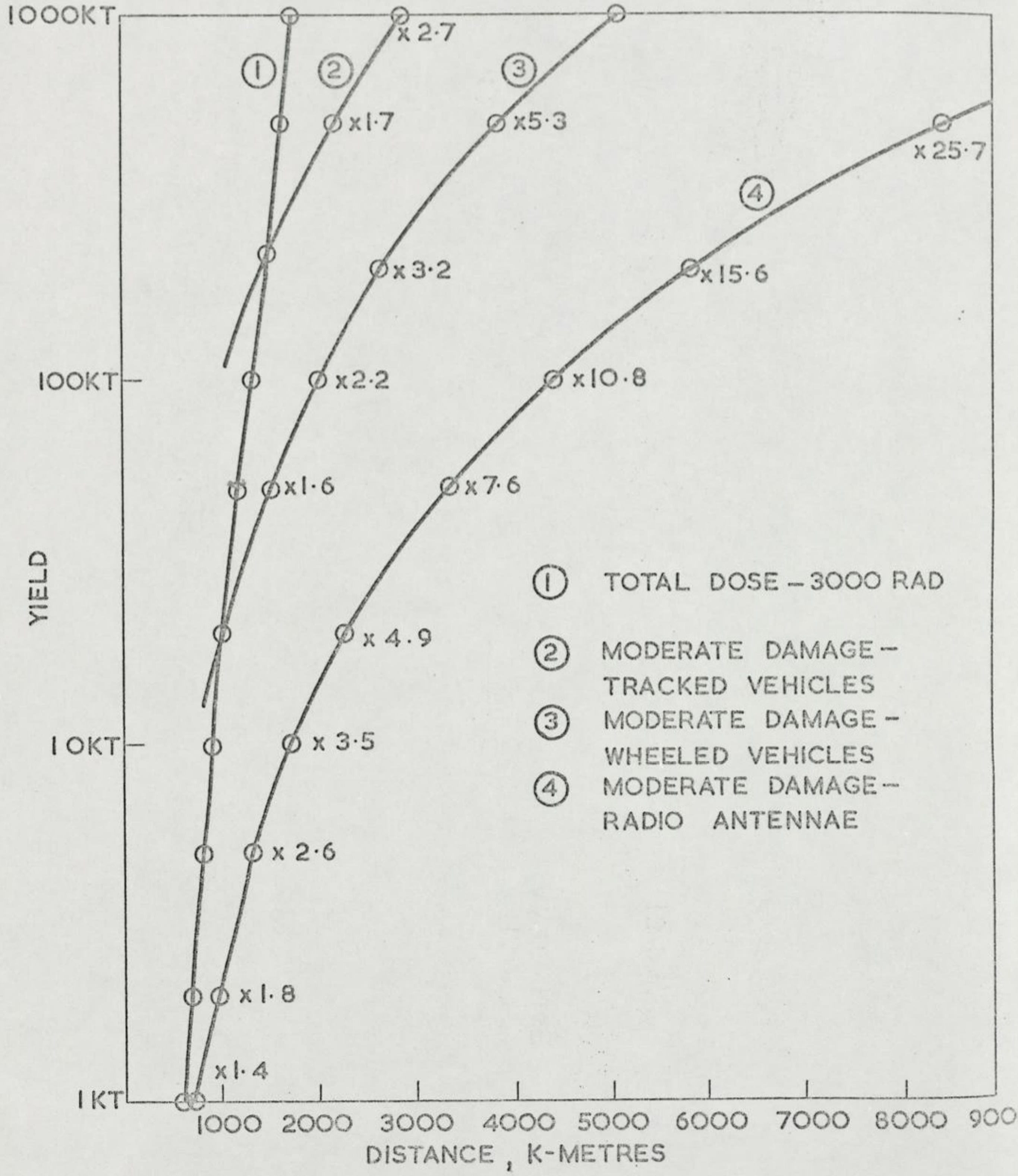
CONFIDENTIAL

FIGURE 1

## PROGRAMME (W.E.S.G.)

| EQUIPMENT | DESCRIPTION | n & γ | THERMAL | BLAST | E.M.P. |
|---|---|---|---|---|---|
| FACE | MOBILE DIGITAL COMPUTING SYSTEM, NORMALLY MOUNTED IN AN A.P.C. | U.S.<br>✓ | | | ✓ |
| C45 No. 1 | GENERAL PURPOSE V.H.F. SET<br>(THERMIONIC VALVES) | ✓ | ✓ | ✓ | ✓ |
| C45 No. 3<br>BID 150<br>(a) LANDROVER<br>(b) A.P.C. | ARTILLERY COMMAND V.H.F. SET WITH SPEECH SECURITY BOX | ✓ | ✓ | ✓ | ✓ |
| BRUIN<br>BID 200<br>(a) A.P.C.<br>(b) 'B' VEHICLES | MOBILE TANK COMMUNICATION SYSTEM<br>AERIALS (1) 40ft TELESCOPIC MAST<br>(2) C50 ANTENNA<br>(3) C70 ANTENNA | ✓ | ✓ | ✓ | ✓ |
| CLANSMAN<br>(1) ANTENNAE<br>(2) PRC 350 | HF/VHF RADIO SYSTEMS<br>MANPACK | ✓ | ✓ | ✓ | ✓ |
| ZB 298 | INFANTRY SURVEILLANCE RADAR | ✓ | ✓ | ✓ | ✓ |

CONFIDENTIAL



VULNERABILITY SHADOW AREAS FOR VARIOUS BLAST DAMAGE CURVES. REFERRED TO SHADOW AREA FOR 3000 RAD AS UNITY

FIGURE 2

CONFIDENTIAL

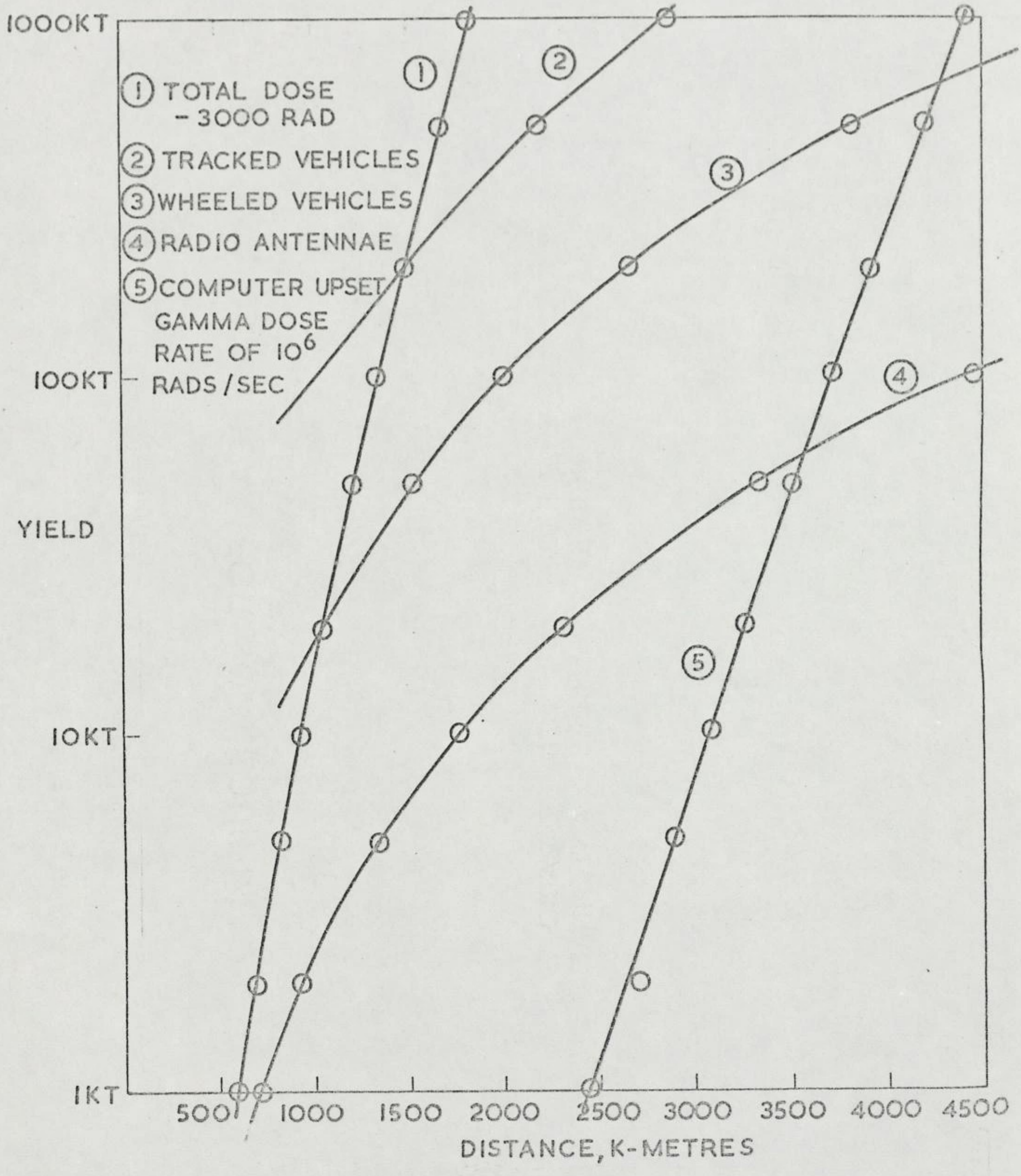
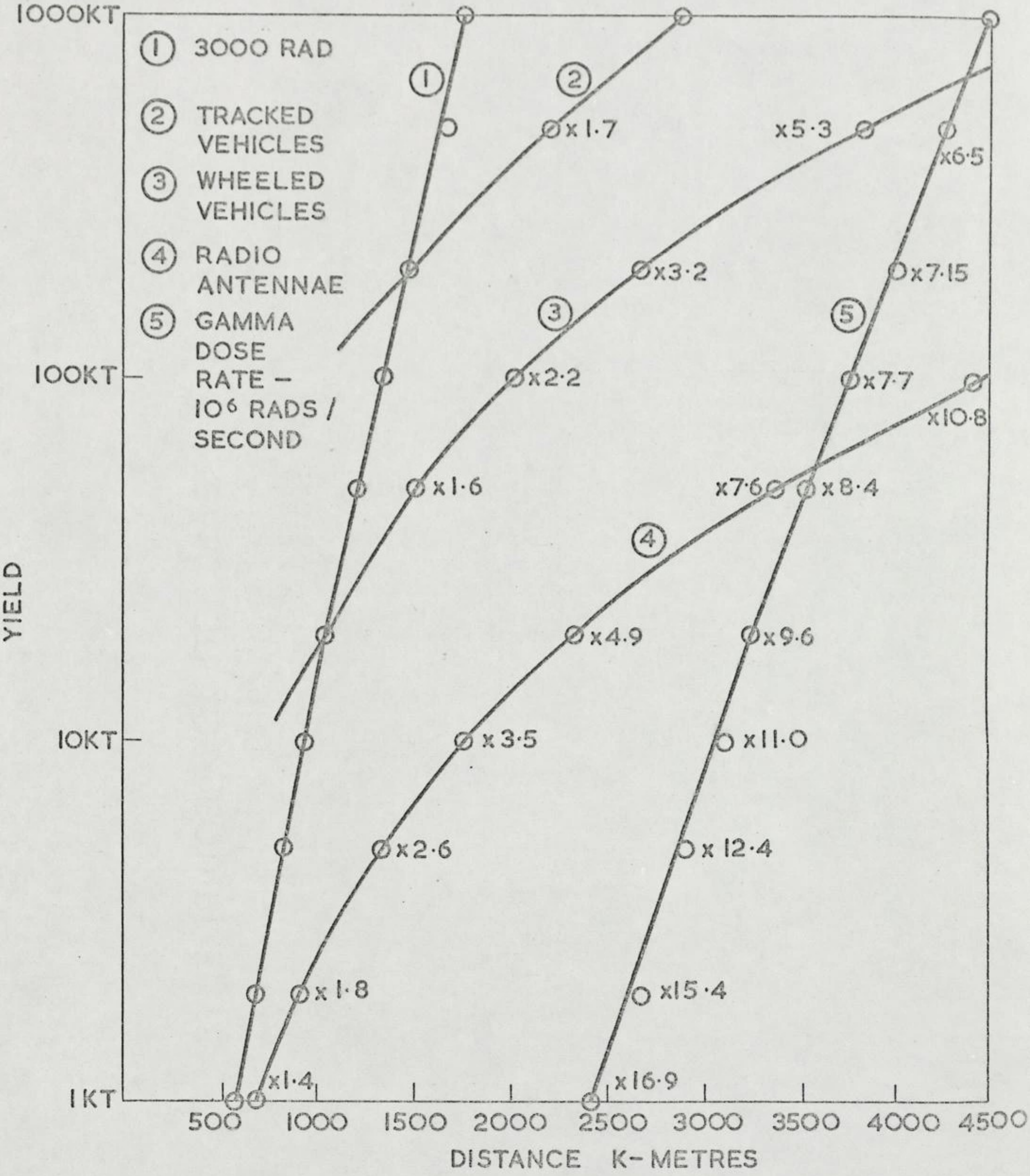


FIGURE 3

K-

CONFIDENTIAL

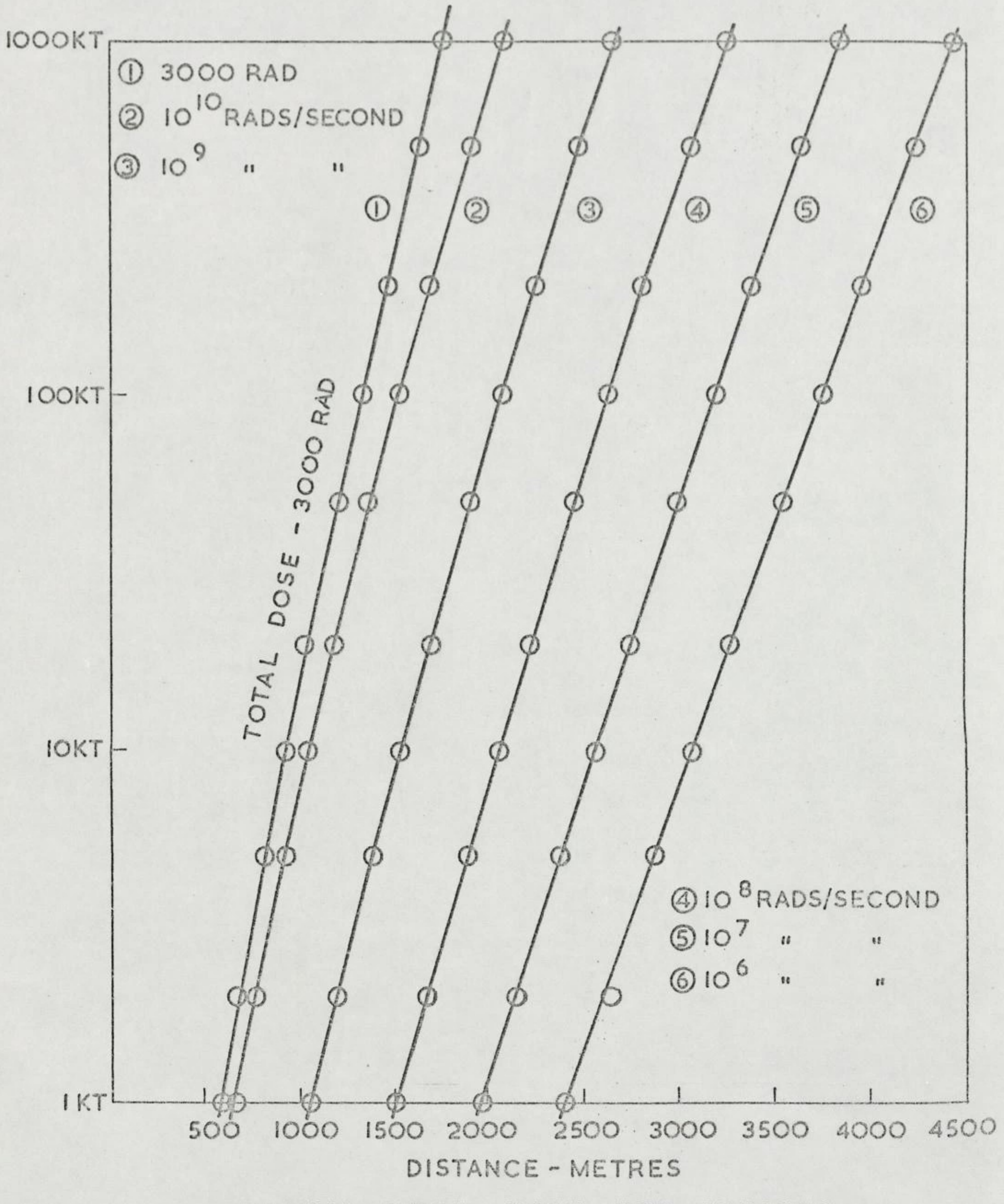
CONFIDENTIAL



VULNERABILITY SHADOW AREAS FOR VARIOUS YIELDS AND DISTANCES

FIGURE 4

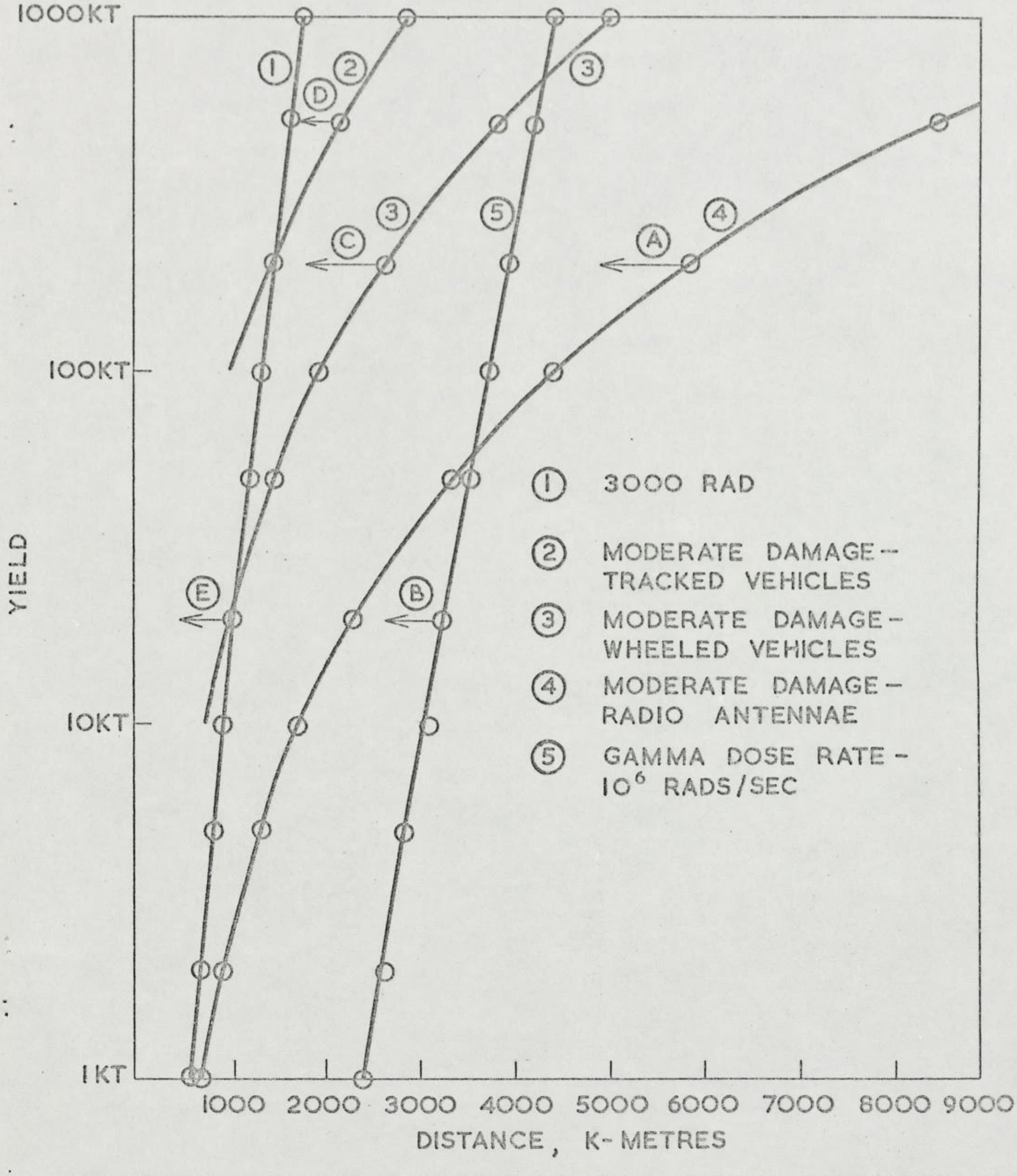
CONFIDENTIAL



GAMMA DOSE - RATE FOR VARIOUS YIELDS AND DISTANCES

FIGURE 5

CONFIDENTIAL



SUGGESTED STEPS TO PROGRESSIVELY REDUCE VULNERABILITY SHADOW AREAS Ⓐ → Ⓔ

FIGURE 6

CONFIDENTIAL

CONFIDENTIAL

# SHADOW AREAS FOR TWO BOUNDARY CURVES – 300 RAD AND $10^6$ RADS / SECOND – YIELD 50 KT

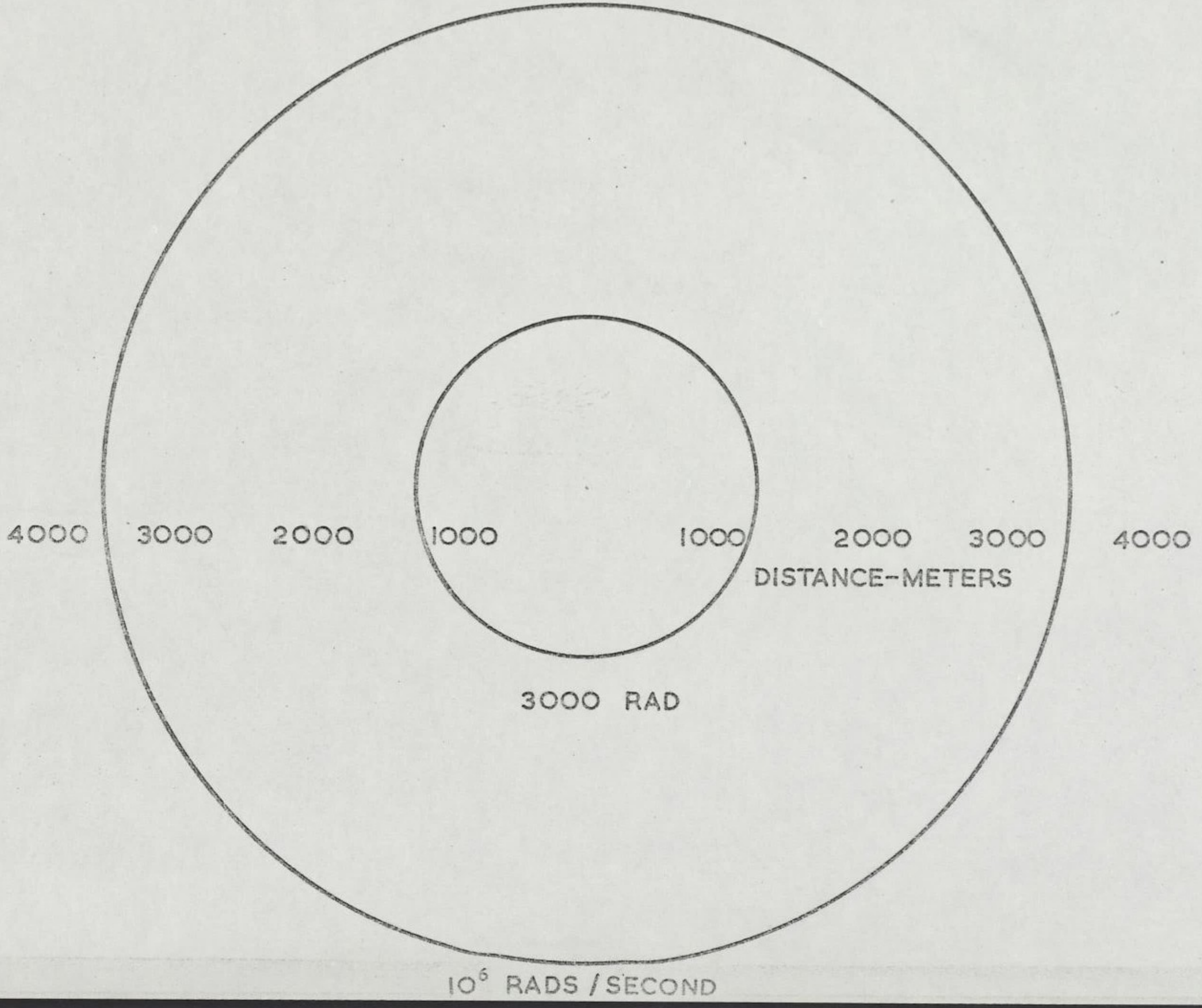


FIGURE 7

CONFIDENTIAL

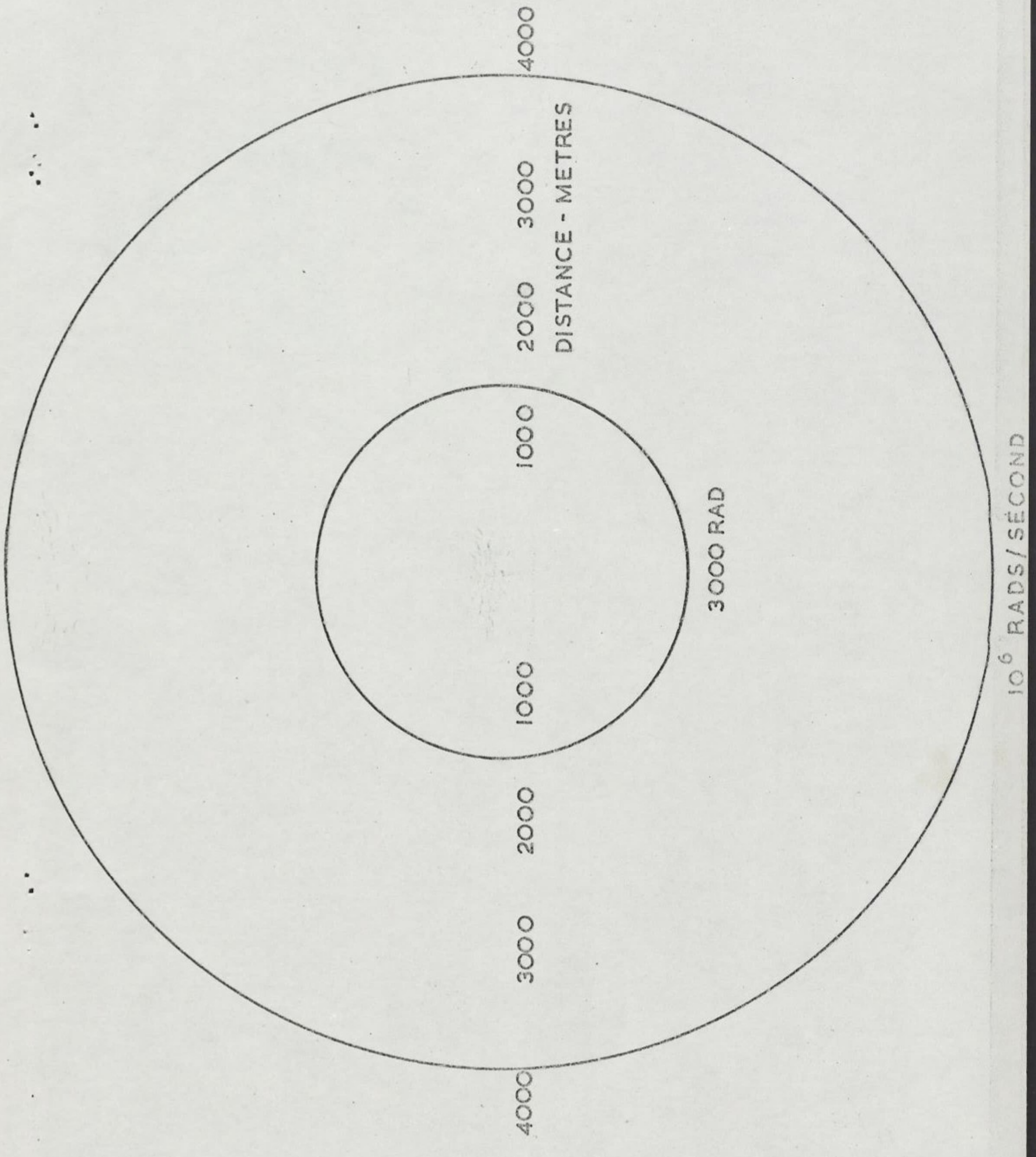

4000
3000
2000
1000
1000
2000
3000
4000
DISTANCE - METRES
3000 RAD
$10^6$ RADS/SECOND

FIGURE 8

FIGURE 9

# TOTAL SHADOW AREAS FOR 100 EQUIPMENTS AND VARIOUS BOUNDARY CURVES EXPRESSED AS PERCENTAGE OF CORPS AREA (80 KM x 160 KM)

| | 3000 RAD | TRACKED VEHICLES | WHEELED VEHICLES | RADIO ANTENNAE | $10^6$ RAD/SEC |
|---|---|---|---|---|---|
| 20 KT | 2·7% | | | 13·2 % | 26·1 % |
| 50 KT | 3·6% | | 5·6 % | 27·5 % | 30·4% |
| 200 KT | 5·4% | | 17·3 % | 83·4 % | 38·3% |
| 500 KT | 6·8% | 11·7% | 36·0% | 174·0% | 43·7% |

ANNEX A

# NUCLEAR HARDENING SYMPOSIUM

## REVISED PROGRAMME

| Serial | Time | Event | Responsible |
|---|---|---|---|
| 1. | 1045 - 1100 | Introduction | D/RARDE |
| 2. | 1100 - 1115 | Nuclear Weapon Concepts | Mr G C Scorgie, AWRE |
| 3. | 1115 - 1130 | Effects of TREE and EMP on Electronic Equipment | Mr E T Jenkins, AWRE |
| 4. | 1140 - 1155 | The Derivation of Survivability Criteria | Lt Col D W B Williams, AWRE |
| 5. | 1155 - 1210 | Army Policy on Nuclear Survivability | Lt Col G G Carter, OR 4. |
| 6. | 1210 - 1230 | Results of studying survivability at RARDE and elsewhere | S/A3<br>Mr Davies, AWRE |
| 7. | 1230 - 1245 | Options on existing equipment | Lt Col G G Carter, OR 4 |
| 8. | 1245 - 1415 | Lunch | |
| 9. | 1415 - 1430 | Summary and key problem~~s~~ areas | PS/A |
| 10. | 1430 - 1530 | Discussion Panel | D/RARDE |

1-11-71.

E40/2.

MINISTRY OF DEFENCE
D. Sc 3
19 NOV 1971
FILE 104/11/10

## EFFECTS OF TRANSIENT NUCLEAR RADIATION (TREE) AND THE ELECTROMAGNETIC PULSE (EMP) ON ELECTRONIC EQUIPMENT

E T Jenkins

AWRE Aldermaston

### INTRODUCTION

The purpose of my talk is to present an impression of the effects that neutron and gamma fluences and, the electromagnetic pulse from nuclear explosions have on electronic equipment. I also want to draw attention to the consequences as they affect the designer and the user of equipments. The radiations submit the equipment to a transient environment but the effects may be transient or permanent. Generally, the effect of the neutron pulse is always permanent and cumulative. Permanent effects from the gamma pulse and EMP pulse at the levels of concern are secondary conditions brought about by the transient primary effect.

DS
KRh
WN3
Log.

### TRANSIENT NUCLEAR RADIATION

Nuclear radiations induce changes in all materials but, at the levels with which we are concerned, based on the 3,000 Rads man survivability criterion the effect on electronic components other than semiconductors can, with rare exceptions, be ignored. The fluence range of interest for neutrons is from $10^{11}$ neutrons/sq $cm^2$ to a few x $10^{12}$ neutrons/sq $cm^2$. The gamma dose range is from approximately 500 Rads to 2,500 Rads with peak dose rates from approximately $10^8$ Rads/sec to $10^{11}$ Rads/sec. The diagram D1 shows how the ratios of neutrons and gammas contained in 3,000 Rads relate to weapon yields.

### THE p-n JUNCTION AND THE EFFECT OF NUCLEAR RADIATION

Semiconductor components function because of the properties of the junctions between semiconductor materials having + ve ion impurities and - ve ion impurities. The junctions are known as p-n junctions and the currents that flow across junctions depend on the semiconductor material, the numbers of ions present and on physical forces in the junction region. The changes in the electrical behaviour of semiconductor components are brought about by two fundamental radiation effects changing the conditions in the bulk of the material and in the junction region. The two effects are Displacement Effects and Ionisation Effects. Displacement refers to the physical damage produced when neutrons knock on atoms from their normal lattice positions to other locations. Ionisation is the knocking of orbital electrons from atoms by gamma radiation to form ionised atoms and free electrons.

## EFFECTS OF NEUTRONS

Displacement damage results in changes being brought about to the characteristics attributed to specific semiconductor transistors and diodes, hence distorting, or completely changing a circuit performance. The most serious effect is the degradation in the current gain of transistors, a parameter of great importance to a designer influencing such features as degrees of amplification, voltage and current levels, switching times and so on. Other effects like, increase of junction reverse current and increase of forward voltage drop in diodes and saturation voltages in transistors are usually not such serious problems.

The degraded gain for a specific component can be estimated from the relationship given by:

$$\frac{1}{\beta} = \frac{1}{\beta_o} + K\phi$$

where $\beta_o$ = gain before irradiation

$\beta$ = gain after irradiation

K = damage constant, a measured value

$\phi$ = neutron fluences in n/sq cm$^2$

If a designer is provided with knowledge of K, the damage constant, for the components necessary for his design he can determine the extent to which a specified neutron fluence level can affect the design performance and he can then take steps to harden his design.

The degraded gain obtained from the formula is a permanent value. At the time of the neutron pulse there is a prompt degradation of gain to a much lower value, equal to the permanent value which would result from exposure to 5 times the neutron fluence to calculate the final value. An annealing process restores the gain to the permanent degraded value in a period 10 to 100 seconds but, if an equipment has to operate through the neutron burst, this transient degradation has to be taken into account.

Neutron damage is cumulative so that an equipment could survive one dose but fail under subsequent doses.

## GAMMA EFFECTS

The primary effect of gamma radiation on diodes and bipolar transistors is a transient one for the doses of interest to us. Furthermore, it is the effect of the dose rate that is important since this determines the degree of ionisation taking place and the resulting flow of primary photocurrents across p-n junctions at a given instant. The value of the primary photocurrent in a junction is the sum of two components, the drift photocurrent and the diffusion photocurrent. The value of the primary photocurrent can be predicted from the equation:

$$I_{pp}(t) = Y \left\{ q\,g\,A\,w + q\,g\,A\sqrt{D\tau}\left[ (\mathrm{erf}\left(\frac{t}{\tau}\right)^{\frac{1}{2}} - \mathrm{erf}\left(\frac{t - t_p}{\tau}\right)^{\frac{1}{2}} \right] \right\}$$

where $Y$ = dose rate (Rads/sec)

$q$ = electronic charge $1.6 \times 10^{-9}$ coulombs

$g$ = generation constant electrons/hole pair/$cm^3$/Rad

$3.9 \times 10^{13}$ Si

$11.5 \times 10^{13}$ Ge

$A$ = junction area ($cm^2$)

$w$ = depletion width (cms)

$D$ = diffusion constant for minority carriers $cm^2/sec$

Si N = 12 Si P = 30

Ge N = 48 Ge P = 98

$\tau$ = minority carrier life-time (secs)

$t_p$ = pulse duration

$t$ = time at which $I_{pp}$ is given.

In the expression $q\,g\,A\,w$ is the drift component and $q\,g\,A\sqrt{D\tau}$ is the diffusion component.

Computing the value for a device involves estimating (measuring) the junction area, the width of the junction from capacity measurements and reverse recovery storage time to obtain the minority carrier life-time.

The predicted generation of primary photocurrent will be modified by circuit conditions to produce a much larger current flow through the transistor known as the secondary photocurrent. This can produce component burn-out, false switching and can result in a disturbance situation developing that could last for an appreciable time after the radiation pulse has ceased, and could leave a circuit in a damaged or altered state.

## INTEGRATED CIRCUITS

I want, very briefly, to draw attention to the effects of radiation on integrated circuits in view of their great importance for projected and future command and control systems. IC's incorporate bipolar transistors, diodes and diffused resistors on a monolithic, junction isolated, semiconductor substrate. The substrate forms additional p-n junctions associated with the collectors of individual transistors and these add to the photocurrents generated by gamma radiation. Junction-isolated bipolar IC's are reasonably hard to neutron damage and likely to be satisfactory for doses up to $\sim 10^{14}\ n/cm^2$. Gamma radiation can cause a change in the output state of a device so as to switch the device it is driving and since IC's are often used as drivers for stores, a store can be corrupted. The malfunction level is, typically, a few x.$10^8$ Rads/sec.

The Metal Oxide Field Effect Transistor, a unipolar device whose action depends on majority carriers only, is particularly suitable for large scale integration. It is however prone to permanent damage by total gamma doses in excess of $10^4$ Rads. MOST devices are also high impedance devices and for this reason transient effects become noticeable at about a few x $10^7$ Rads/sec, an order lower than bipolar IC's.

AIDS TO ACHIEVE SURVIVABILITY

Designers are becoming aware that changes in component characteristics will occur and will affect performance. An electronic circuit design is initiated by the functional requirements of the system supplemented with a list of components and their radiation characteristics. AWRE is currently engaged in establishing a data bank of information of available discrete and integrated circuit devices. From the designers point of view it is important to supplement this information with inspection schemes to select components whose radiation characteristics can be relied upon: if quality control in device technology is allowed to wander the radiation tolerance could be variable and the data provided not valid.

Circuit design behaviour under radiation pulses can be undertaken as the design develops by use of computer circuit analysis programmes that have been developed specifically for the purpose. SCEPRE, TRAC, NET, CIRCUS and ECAP II are all suitable to varying degrees for use with discrete components.

Designs should be tested in simulated environments and checked against the response analysed for the Simulator environment. The nuclear burst pulse will be different but an analysis of the circuit response to this should be undertaken and if this indicates satisfactory performance then, provided the Simulator pulse test and Simulator pulse analysis result tally, the designer can be confident that his circuit will be hard. It may be thought desirable to undertake underground nuclear testing to check the response of really vital equipment. Simulators that are currently available are:-

LINAC - for r tests on components and small circuit boards

EROS - for pulse r simulation tests on equipments

HERALD reactor - for neutron damage constant evaluation

VIPER - for pulse neutron simulation tests on equipments

## R & D

Designers can achieve a degree of hardening by careful selection from currently available components. Because of the need to store data a hardened range of IC's is required and hardened Bipolar and Unipolar varieties are being developed in the US. The methods involve the isolation of individual devices on a chip by means of layers of solid dielectric materials such as Silicone Dioxide, ruby or saphire. In the UK the development of the technologies for Bipolar devices is being undertaken by CVD at Hirst Research Centre and Plessey Caswell laboratories.

A great deal of work is being done in the US and a little at AWRE to improve the mathematical representation of semiconductor device models to provide greater prediction accuracy and to formulate a systems analysis programme for Integrated Circuit design.

It seems likely that the AWRE Simulators could be overloaded in the not too far distant future. Costs of providing additional facilities ought perhaps to be investigated. Lasers offer an alternative low cost facility to LINAC machines for component tests and acceptance control.

A designer having hardened to the limits possible may still be baulked, in achieving the system goal. In this case he has to resort to circumvention techniques to detect the presence of Radiation at low level and render his equipment inoperative. The need here is for components specially sensitive to radiation to act as detectors.

## EMP EFFECTS

The fields coupling with equipment as a result of the Electromagnetic Pulse may be plane waves with a transverse electric mode as from an exoatmospheric burst, or may be inductive if the equipment is near to the source of an endoatmospheric burst. The coupling energy induces spurious voltages and currents superimposed on the functional designed levels and hardening equipment against EMP aims to minimise the degree of coupling and reduce the spurious impulses to a safe level.

## COUPLING MECHANISMS

The coupling of energy into equipment is dependent upon its orientation and geometric configuration with respect to the field. Electrical equipment is usually in the form of metallic boxes connected by cables. The boxes and cables may be within metallic vehicle containers which are exposed to the field or may be directly exposed. Cables can vary from a few inches to a few miles. Equipment in enclosed vehicles is exposed to secondary fields and the character of this field depends on the degree of complete enclosure possible.

Primary fields are concentrated at the corners of boxes and containers and large secondary fieldscan result within such boxes if apertures are situated near to corners.

Direct coupling through metallic walls can occur, the degree being dependent on the duration of a pulse, the conductivity of the wall, its thickness, the wall material and the relative permeability. There is a delay time before currents can exist on the inside of walls and cause secondary internal fields and this fact is noteworthy for a designer.

High currents can be developed in metallic elements or rods crossing equipotential planes of the electric field. Where continuous loops enclose magnetic fields the resultant currents will have the form of the incident field shape. Open loops produce large potentials across terminals.

Re-radiation within containers is possible due to the interaction of currents brought in by cables with the fields.

## THE EFFECT OF EMP ON EQUIPMENTS

Temporary and permanent effects can be caused by the EMP pulse. Semiconductors may break-down because of the absorption of too much spurious energy. Voltages appearing on the HT lines in digital systems may cause latch up conditions in integrated circuits to invalidate the integrity of stored information. Open loop conditions may introduce potentials causing break-down of small gaps such as miniature relay contacts.

## METHODS TO REDUCE VULNERABILITY TO EMP

A good starting point is to ensure that the shielding of equipment and vehicles is sound. Aluminium and copper skins are effective from a few kHz upwards but some ferrous shielding is necessary below a few kHz and, since the range of frequencies in the spectrum is extensive, sandwich construction may be necessary.

Good electrical bonding of panels, hinges and doors is necessary and doors of vehicles and boxes should not be left open.

Shapes exposed to primary fields should be simple and seams should be smooth and well bonded. Cables should all enter through a single aperture.

Equipments inside vehicles should be mounted away from the walls to avoid coupling with internal skin currents.

Filters should be incorporated in cables at the point of entry into vehicles.

EMP detectors should be considered as an indication of the possible need to re-programme stored information.

## IMPORTANCE OF TESTING

Because of the complexity of the layout of equipment exposed to EMP and the impossibility of shielding completely, equipment must finally be assessed by exposing it to a simulated environment. The most satisfactory method is to generate full scale EMP fields and expose the complete equipment. Failing this, equipment can be exposed to low level pulse fields or continuous waves and the likely behaviour under a full scale pulse assessed by extrapolation. Since the low level techniques involve extrapolation over several orders of magnitude considerable detailed analysis is involved.

A Simulator known as PETS I (pulsed e/m threat simulator) has been constructed and can be used to test small service equipment. PETS I is essentially a two plate transmission line with a working volume 13.5 metres long, 3 metres high and 4.5 metres wide. The diagram gives an impression of what can be done. A bigger version PETS 2, having a working volume 25 metres long, 6 metres high and 11 metres wide is under construction. A vertical monopole radiating system to illuminate a large area such as a communication system has also been constructed to simulate the exoatmospheric pulse. Because of the need for a uniform field the radiation is operated from a distance and the field strength is considerably reduced and extrapolation is extensive. The diagram gives an impression of the monopole system.

CONCLUSION

TREE and EMP have similar effects in that both disturbances produce transient voltage and current pulses to cause damage or malfunction. It is the job of the equipment designer to minimise the effects in his design. The limits to what a designer can do is decided by the financial limits imposed upon actions that he might contemplate, by the inherent limits of components with which he has to work and by the extent of the testing facilities available to him. It is not possible, as a practical proposition, to reduce TREE effects very much by screening. Good screening can reduce EMP effects to negligible proportions.

B/EM

Reference AV 583/050 1/11/71.

A07/104/11/10

E40/1.

ONE DAY PRESENTATION ON THE EFFECTS OF NUCLEAR RADIATION ON AIRCRAFT AND EQUIPMENTS

15 November 1971 Commencing at 10.45 hrs.

The intention of this presentation is to create an awareness of the problems likely to arise with aircraft and their associated electronic systems when operated in a nuclear environment. In the short time available for this series of lectures only a broad understanding of the problems likely to be encountered by aircraft design engineers can be given. However it is in the interests of all concerned that these problems are appreciated from the onset of new projected aircraft and to a certain extent on aircraft currently in the design phase.

This is of particular importance to project branches in relation to cost effectiveness if the "Staffs" require an aircraft to operate in a nuclear environment.

| | Subject | Presentation Contribution | Approximate Time |
|---|---|---|---|
| 1. | General introduction on nuclear weapon effects. | RAE | 30 mins |
| 2. | RAF Scenario | OR30 | 30 mins |
| 3. | TREE - discussion of effects on systems | AWRE | 45 mins |
| 4. | LUNCH | | 12.30hrs - 14.15hrs |
| 5. | EMP - 1 Effects on aircraft systems<br>2 Means of counteracting effects | ~~AWRE~~ RAE | 20 mins<br>25 mins |
| 6. | Information, further education etc | DSc6 | 10 mins |
| 7. | Period of discussion. | | 45 mins |

Estimated dispersal timing 16.00 hrs.

MINISTRY OF DEFENCE
D. Sc 3
16 NOV 1971
FILE 104/11/10.

DS.
RK.
WGS.
Log.

E40

WNS

Log

Text for talk on "Weapon Outputs" to be given on
1 December at RARDE symposium on nuclear hardening
G C Scorgie, AWRE Aldermaston

## 1. Introduction

This is to be a brief recapitulation of nuclear weapon outputs, not in order to set down definitive numbers, but in order to establish background for the subsequent discussion. In these circumstances there is nothing to be gained by recounting a mass of numerical data. The purpose of this part of the proceedings will be best served if I confine myself to recalling the main influences that emerge from a nuclear weapon, saying something of the terminology involved; and, if time permits, setting the perspective in such matters as the way in which the relative importances of these effects vary as the energy released in the explosion is varied.

## 2. Constituents of the nuclear environment

Let me begin by listing the main constituents of the nuclear environment in the context of Army equipment. The constituents are

air blast

heat

nuclear radiations (neutrons and gammas)

EMP (electromagnetic pulse)

ENT 1/11/71

MINISTRY OF DEFENCE
D. Sc 3
3 NOV 1971
FILE 104/11/10

And to fix ideas the configuration comprises a bomb of yield WkT burst at height H, and a target at range R from ground zero.

Of course near to ground zero (say R of a few hundred feet and W of 1 kT) a target would be engulfed in the fireball; but as I don't imagine you contemplate hardening to this level no more need be said about it.

## 3. Blast and heat

Blast and heat we can pass over very quickly -- not because they are unimportant but because their natures and the terms in which they are described are within our everyday experience. Very briefly the airblast is a pulse of pressure accompanied by a wind, the pulse rising very sharply and falling off in a time of order a second. It is worthwhile noting that the blast wind, though brief, reaches rather high speeds, values of a few hundreds of miles per hour being typical. In fact for much Army field equipment it is the blast wind that does the damage, rather than the crushing produced by the overpressure which is typically several lb in$^{-2}$.

The heat is delivered by thermal radiation, again in a pulse rising sharply and falling off in a time of order a second. The total heat falling on unit area of a target is expressed as so many cal $cm^{-2}$, but it is important to note that this number alone is not enough to indicate the potential for damage. For that we need to know not the total heat but rather the rate at which heat is delivered to the target -- the cal $cm^{-2}$ $sec^{-1}$. The reason is obvious -- the heat being delivered is in competition with the heat being lost by conduction into the body of the target and by other routes. Hence to reach damaging temperature we must pump in the heat fast enough. The importance of rates rather than total quantities will come up again shortly in connection with one component of nuclear radiations.

Typical numerical values for the thermal case are a total flux of a few tens of cal $cm^{-2}$ delivered in a time of order 1 sec, with a peak delivery rate, in cal $cm^{-2}$ $sec^{-1}$, that is several times the total flux in cal $cm^{-2}$. For example the peak rate associated with, say 25 cal $cm^{-2}$ might be around 100 cal $cm^{-2}$ $sec^{-1}$.

## 4. Nuclear radiations

Turning now to nuclear radiations, the important constituents are neutrons and gamma rays. And the difficulty in getting any sort of feel for this aspect of things is that neither of these nuclear emissions is within our conscious experience. For what it is worth, gamma rays are like X-rays, only more penetrating; and a neutron may be thought of as a bullet having a mass of the order of atomic masses. Like any other bullet the damaging capabilities of the neutron depend on its speed, and speeds are commonly of order some thousands of miles per hour. Even at these speeds the energy carried by a neutron is so small that many millions are needed to produce significant effects. The scale is best established by referring to one of the more sensitive components in the battle area -- the soldier. A soldier exposed to a neutron flux of order $10^{12}$ n $cm^{-2}$ will slowly fall sick and ultimately die, although the battle may well be over long before death occurs.

Of course what has injured the soldier is the energy that his body tissue has absorbed from the incident neutrons. This is an intricate question and all we need note is that the unit of absorbed energy is the rad. Again to set the scale we may note that $10^{12}$ n $cm^{-2}$ corresponds roughly to an absorption of about 2000 rad.

Turning to gamma rays, they are characterised also by the energy that they carry, but again what matters is the energy absorbed; and the unit here also is the rad.

In fact, so long as we are dealing with the effects of neutrons and gamma rays on men we may express both in terms of rads and just add them together. The total absorption of 3000 rad, which is something of a central number in current Army thinking, is then experienced at about 1000 yards from a 10 kT burst.

In view of the central role which the Army attaches to nuclear radiations in discussions of hardening I would mention an important feature, namely the steepness with which the nuclear radiation dose falls as we recede from the bomb. This arises from the interaction of these radiations with the air. What matters to the soldier, I suppose, is the distance out to which a given effect expressed in military operational terms is achieved. If at one time the experts say it takes 3000 rad to do this, does it matter if they subsequently say it really takes 2000 rad or perhaps 5000 rad? Well the saving grace here is the steepness of the curve I've just mentioned, for only a modest proportional change in distance corresponds to quite a substantial change in nuclear radiation dose. And because blast, heat and EMP vary less sharply with distance from the bomb, the numbers expressing those aspects of the nuclear environment are not very sensitive to quite substantial changes in ideas as to what nuclear radiation dose is needed to achieve a given military objective.

So far I have spoken only of the effects of nuclear radiations on man, and by implication I may have given you to understand that what matters is the dose, the rate of delivery being unimportant. When we consider effects on electronic equipment this state of affairs is substantially true for neutrons but is no longer true in all circumstances for gamma rays. Very briefly the reason is that, whereas neutrons act mainly by displacing whole atoms which either remain displaced or return only very slowly, gamma rays produce electrical charge effects which are neutralised quite quickly. Hence, much as in the case of thermal radiation, we have two competing effects, and the rate at which we pump in gamma rays is what counts in many instances.

It is quite a complicated matter to follow the course of gamma production by a nuclear explosion, and I don't intend to attempt it here. The important point is that at a very early stage the rate of production is very high for a very brief period that is measured in hundredths of a microsecond. For example, at 1000 yards from 10 kT the peak dose rate may be of order $10^9$ rad $sec^{-1}$. To set the scale, we may note that some electronic equipment can be adversely affected at rates of order $10^7$ rad $sec^{-1}$. This latter number points to a somewhat startling conclusion. For if $10^7$ rad $sec^{-1}$ is maintained for a few hundredths of a microsecond the dose absorbed in this time is only a few tenths of a rad; yet the equipment may be at hazard. Of course it must be noticed that the few tenths of a rad is only a small part of the total dose that will be experienced; and certainly it is the larger total dose that may determine the response of other aspects of the target complex. Yet when allowance has been made for this fact it remains true that some ystems can be adversely affected by gamma dose rate effects at levels of total dose that are quite innocuous.

## 5. EMP

Next I have to steel myself to say something about EMP. I say "steel myself" because no other aspect of the emanations from a nuclear weapon has proved so difficult to describe in a way that is concise, quantitative and comprehensive. In fact these three aims are incompatible. I'll make sure of being concise; I'll be very roughly quantitative; and I'll make no attempt to be comprehensive.

The electromagnetic pulse as its name suggests is a coherent pulse which rises very sharply, in a time of a few tens of nanoseconds, and lasts, depending on circumstances, for a time ranging from several tens of nanoseconds to hundreds of microseconds. Being an electromagnetic phenomenon it is described in terms of electric field strength in volts per metre and magnetic field strength in amperes per metre. What it does to a target is in principle very simple: the electric field causes electric currents to flow and it is these currents that cause the trouble; though in many cases irreversible damage does not result. In order to appreciate the rationale for a broad classification that I shall now make you need to know that the EMP is caused by the absorption of radiation (chiefly gamma rays) in the atmosphere.

There are then two cases according as the bomb is exploded low down in the atmosphere or high up. With the low burst the gamma ray absorption and consequent EMP generation occur locally. With the burst at high altitude, where the air is very tenuous, the gamma rays travel considerable distances before being absorbed. Thus for bursts at a height upwards of 50 km, say, the EMP production takes place in an extensive layer at around 30 km altitude.

In certain respects the pulses from the two types of burst are quite comparable; thus rise times and peak amplitudes are of order tens of nanoseconds and tens of kilovolts per metre respectively. The duration of the high altitude EMP is significantly shorter than that of the low altitude EMP. But the outstanding difference between them is to be found in the extent of ground surface over which they have large intensity. For the low altitude burst this distance is typically a few kilometres, whereas it is a few hundreds of kilometres in the case of the high altitude burst.

## 6. Influence of bomb yield

Finally I should say something about the way in which the relative importance of these various emissions changes with the yield of the bomb. Broadly speaking, and omitting EMP for the moment, at low yields the nuclear radiations predominate in the sense that their damage range extends further than those of blast and heat. At somewhat higher yields blast takes over as the most extensive influence. And at the highest yields thermal radiation predominates.

EMP is in a sense the odd man out because its dependence on yield is very weak. It depends much more on the configuration in which the bomb is exploded. These facts are perhaps most vividly brought out by the realisation that in homogeneous surroundings no EMP would be produced no matter how great the yield of the bomb.

E39/1

UNITED KINGDOM ATOMIC ENERGY AUTHORITY

ATOMIC WEAPONS RESEARCH ESTABLISHMENT
Army Element, Building D29
Aldermaston, Reading, RG7 4PR
Telephone Tadley 4111 (STD 07 356 4111)

covering CONFIDENTIAL

Ext: 7731
Our Ref: AWRE/ARMY/R2/2/2(W)
Your Ref:
Date: 25 October 1971

NUCLEAR SURVIVABILITY
RARDE SYMPOSIUM 1 Dec 71

Enclosed is a copy of the draft script for the item

"The Derivation of Survivability Criteria"

D W B WILLIAMS
Lt Col
SMR

Enclosure:

1. One Copy of Script

Distribution:

Colonel D E ISLES, OBE - RARDE
Mr W N SAXBY - MOD D Sc 6
Lt Col G C CARTER - MOD GS(OR)4
Mr D J GARRARD - MOD (PE), LTP16
Mr J D DAVIES - AWRE
Mr G C SCORGIE - AWRE

WNS
Log

MINISTRY OF DEFENCE
D. Sc 3
3 NOV 1971
FILE 104/11/10

covering CONFIDENTIAL

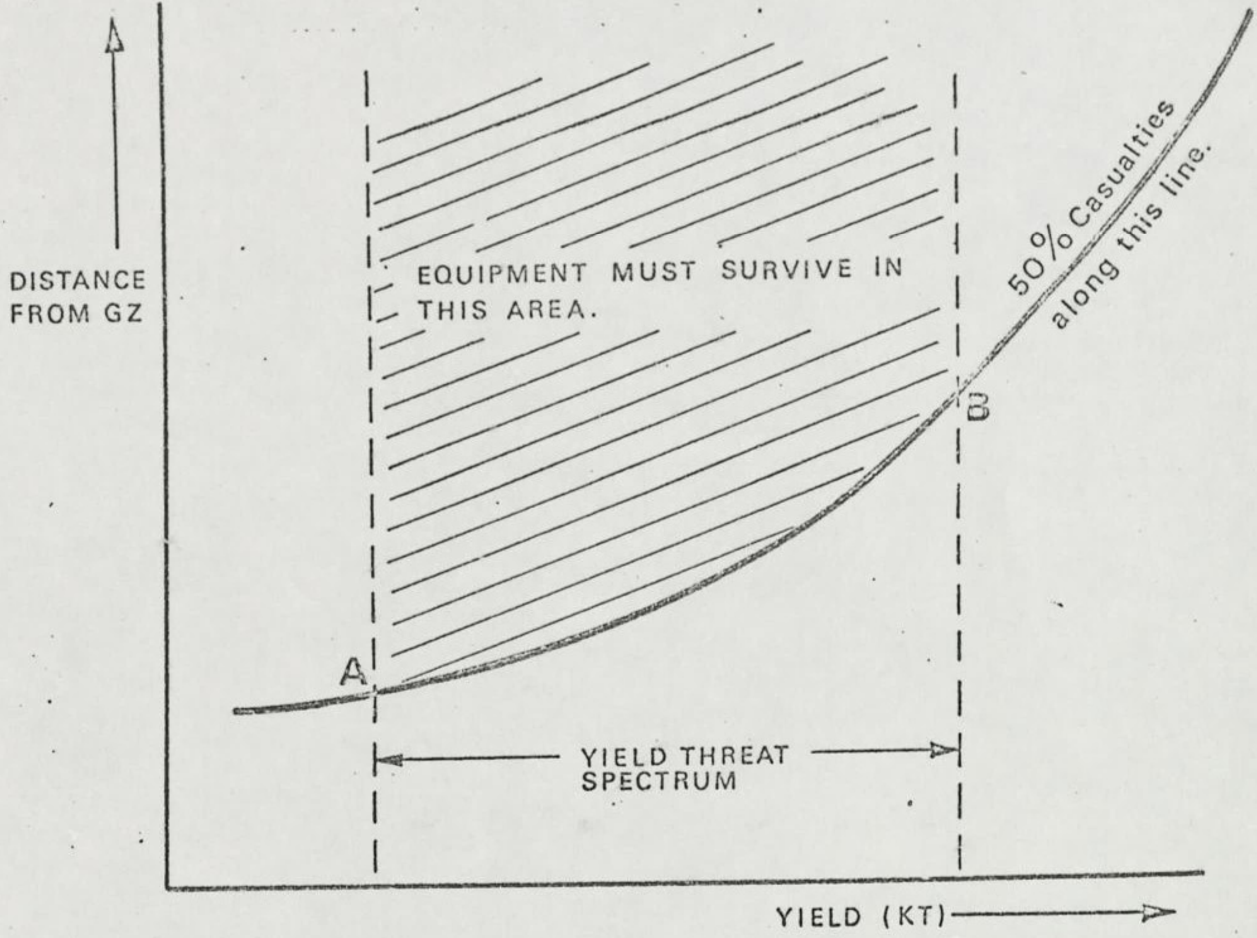


FIGURE 2. THE FORM OF THE GRAPH OF THE DISTANCES FROM GZ AT WHICH MEN ASSOCIATED WITH THE EQUIPMENT HAVE A 50% CHANCE OF SURVIVING FOR 1 HOUR AFTER THE NUCLEAR EXPLOSION. THE HARDENING CRITERIA ARE THE MOST STRINGENT VALUES OF THE NUCLEAR EFFECTS PARAMETERS CALCULATED ALONG THE CURVE BETWEEN POINTS A AND B.

## PROPOSED HARDENING CRITERIA FOR: ELECTRONIC BLACK BOX IN LIGHTLY ARMOURED VEHICLE
(SPECTRUM 0.1 - 500 kt)

| AIR BLAST | A | B | "Old" Units |
|---|---|---|---|
| Peak static overpressure | 8 | 5 | psi |
| Peak dynamic pressure | 1.3 | 0.5 | psi |
| Positive phase duration | 0.7 | 2.5 | sec |
| Overpressure impulse | 2.1 | 5.1 | psi sec |
| Dynamic pressure impulse | 0.4 | 0.5 | psi sec |

| THERMAL RADIATION | | |
|---|---|---|
| Total thermal flux | 110 | Cal/cm$^2$ |
| 80% energy delivered in | 2.0 | Sec |
| Maximum irradiance | 70 | Cal/cm$^2$ sec |
| Pulse width at half maximum irradiance | 0.8 | Sec |

| INITIAL NUCLEAR RADIATION | | |
|---|---|---|
| Protection factor - neutron and gamma | 1 | |
| Total dose | 3000 | rad (tissue) |
| Maximum gamma contribution | 1000 | rad (tissue) |
| Maximum neutron contribution | 2500 | rad (tissue) |
| (from fission spectrum) | 1.4 x $10^{12}$ | n/cm$^2$ |
| Peak gamma delivery rate (i.e. Dose rate) | 2 x $10^{10}$ | rad (tissue)/se |

### ELECTRO MAGNETIC PULSE (EMP)

| A. Exo-atmospheric Bursts | | |
|---|---|---|
| Maximum electric field | 50000 | volt/meter |
| Maximum magnetic field | 150 | amp/meter |
| Pulse rise time | 10 | nanosec |
| Width at half maximum amplitude | 30 | nanosec |
| Overall pulse duration | 100 | nanosec |

| B. Ground and Low Air Bursts | | |
|---|---|---|
| Maximum electric field | 30000 | volt/meter |
| Maximum magnetic field | 100 | amp/meter |
| Pulse rise time | 20 - 50 | nanosec |
| Duration of plateau after maximum | 200 | microsec |
| Width at half maximum amplitude | 30 | nanosec |
| Electric field at plateau | 10000 | volt/meter |
| Magnetic field at plateau | 30 | amp/meter |
| Overall pulse duration | 500 | microsec |

## PROPOSED NUCLEAR SURVIVABILITY CRITERIA FOR: ELECTRONIC BLACK BOX IN LIGHTLY ARMOURED VEHICLE

(YIELD SPECTRUM: 0.1 - 500 kt)

| AIR BLAST | A | B | SI UNITS |
|---|---|---|---|
| Peak static overpressure | 55 | 34 | kN m$^{-2}$ |
| Peak dynamic pressure | 9 | 3.4 | kN m$^{-2}$ |
| Positive phase duration | 0.7 | 2.5 | s |
| Overpressure impulse | 15 | 35 | kN m$^{-2}$ s |
| Dynamic pressure impulse | 2.8 | 3.4 | kN m$^{-2}$ s |

### THERMAL RADIATION

| | | |
|---|---|---|
| Total thermal flux | 4.6 | MJ m$^{-2}$ |
| 80% energt delivered in | 2.0 | s |
| Maximum irradiance | 2.9 | MJ m$^{-2}$ s$^{-1}$ |
| Pulse width at half maximum irradiance | 0.8 | s |

### INITIAL NUCLEAR RADIATION

| | | |
|---|---|---|
| Protection factor - neutron and gamma | 1 | |
| Total dose | 3000 | rad (tissue) |
| Maximum gamma contribution | 1000 | rad (tissue) |
| Maximum neutron contribution | 2500 | rad (tissue) |
| (from fission spectrum) | $1.4 \times 10^{10}$ | n mm$^{-2}$ |
| Peak gamma delivery rate (ie Dose rate) | $2 \times 10^{10}$ | rad (tissue) s$^{-1}$ |

### ELECTRO MAGNETIC PULSE (EMP)

#### A Exo-atmospheric Bursts

| | | |
|---|---|---|
| Maximum electric field | 50000 | V m$^{-1}$ |
| Maximum magnetic field | 150 | A m$^{-1}$ |
| Pulse rise time | $10 \times 10^{-9}$ | s |
| Width at half maximum amplitude | $30 \times 10^{-9}$ | s |
| Overall pulse duration | $100 \times 10^{-9}$. | s |

#### B Ground and Low Air Bursts

| | | |
|---|---|---|
| Maximum electric field | 30000 | V m$^{-1}$ |
| Maximum magnetic field | 100 | A m$^{-1}$ |
| Pulse rise time | $20 - 50 \times 10^{-9}$ | s |
| Duration of plateau after maximum | $200 \times 10^{-6}$ | s |
| Width at half maximum amplitude | $30 \times 10^{-9}$ | s |
| Electric field at plateau | 10000 | V m$^{-1}$ |
| Magnetic field at plateau | 30 | A m$^{-1}$ |
| Overall pulse duration | $500 \times 10^{-6}$ | s |

N = newton
J = joule
n = neutron

ANNEX TO
D/407/104/11/10/4287

## THE LAND FORCES CONCEPT OF THE NUCLEAR THREAT FOR MATERIEL AND SYSTEMS SURVIVABILITY

1. The nuclear threat to the Land Forces in the forward battle area in North West Europe arises from low air burst $(\text{hob} = 60Y^{\frac{1}{3}}\text{m})$ and ground burst weapons with yields(Y) between 0.1 and 100kt.

2. Within the Corps rear boundary, and behind it, the threat is extended to yields of up to 500kt.

3. In all areas, including UK and those outside NW Europe, Defence materiel and systems are also exposed to the EMP threat from exo-atmospheric ( $\geq$ 35km altitude) nuclear bursts.

Annex A to FCR/872/011
dated 15 September 1971

## NUCLEAR HARDENING SYMPOSIUM

## RARDE, WEDNESDAY, 1 DECEMBER, 1971

### OUTLINE PROGRAMME

| Serial | Time | Event | Responsible |
|---|---|---|---|
| 1. | 1045 - 1100 | Introduction | D/RARDE |
| 2. | 1100 - 1130 | The Nuclear Threat and its implications for Army Equipment | WESG |
| 3. | 1135 - 1150 | The nuclear survivability of FACE | RARDE |
| 4. | 1150 - 1205 | Army Policy on Nuclear Survivability | GS(OR)4 |
| 5 | 1205 - 1220 | Survivability Criteria | WESG |
| 6. | 1220 - 1250 | a. Options on existing equipment<br>b. Problems on future equipment | GS(OR)4<br>RARDE |
| 7. | 1300 - 1415 | Lunch | RARDE |
| 8. | 1415 - 1530 | Discussion Panel on Problems | D/RARDE |

E34/1

RESTRICTED

MINISTRY OF DEFENCE

Royal Armament Research
and Development Establishment
Fort Halstead
Sevenoaks, Kent.

Our Ref: FCR/872/011

Distribution below

15 September 1971

NUCLEAR HARDENING SYMPOSIUM

1. As a result of discussions held at the time of the Review of the RARDE Programme of Work it was suggested by the Chief Scientist (Army) that RARDE should hold a symposium on the subject of nuclear hardening of army equipment.

2. I have therefore arranged for this to take place at RARDE on Wednesday, 1 December, 1971. The aim of the symposium willbe:

> "To identify the threat to army equipment in a nuclear environment and to discuss the problems arising from the requirement to achieve nuclear survivability."

3. A copy of the outline programme is attached at Annex A and you are invited to attend or be represented. I would be grateful if you would inform me if you are able to attend and if not whether you will be represented. Details of arrangements will be sent out at a later date.

4. The security level of the conference will be SECRET.

F H East.
Director

~~DO~~
~~WAS~~ Aw
~~RR~~
Logi

MINISTRY OF DEFENCE
D. Sc 3
23 SEP 1971
FILE 104/11/8/10

EC/44/10/10

CONFIDENTIAL

CONFIDENTIAL

MINISTRY OF DEFENCE

Main Building, Whitehall, LONDON S.W.1

*Telephone:* 01-930 7022, *ext.* 7379

Room 2264

OFC

E34.

*Our Reference:* D/407/104/11/10/4196
*Your Reference:*

FLOAT COPY DESTROYED
7/10/71

Mr J D Davies
AWRE Aldermaston

10 September 1971

Dear John

IMPLICATIONS OF SPECIFYING NUCLEAR SURVIVABILITY CRITERIA FOR ARMY EQUIPMENT - A SYMPOSIUM AT RARDE, 30 NOVEMBER 1971

1. The steering group for the above symposium met today: we were asked to provide, through the WESG/WECC network, 2 speakers.

(A) The Nuclear Threat and its Implications for Army Equipment -(30 minutes at most)

This presentation should be a crisp survey - explaining the terms used, giving a brief "almost popular science" explanation of the effects weighted towards TREE and EMP, giving examples of target response for each effect, generally by reference to equipment, other than FACE, in the Army programme, and finally ending up with a few minutes devoted to the WESG/WECC organisation, and its programme for Army equipment.

(B) Nuclear Survivability Criteria - (15 minutes at most)

This paper is to give succintly the basic philosophy of, and the main steps in establishing, survivability criteria for Army equipment, it should include discussion of the options available including reflection of costs on the decisions.

2. The group, and ourselves in DSc6, will be very pleased if you can see your way to undertake "A", and if Col David Williams would undertake "B". Bob Rankin, Tom Jenkins and Major Barry Burke can expound further on the content of the papers, which it must be remembered are aimed at Director General/Director/Major General/Brigadier levels in MOD(Army) and MOD(PE).

3. Detailed speaking notes are required to be circulated to reach the planning group members by 8 Oct 71 at the latest. The planning group consists of:

Col D. Iles, RARDE Fort Halstead.
Lt Col G G Carter, GS(OR)4 MOD London
Mr E T Jenkins, SSWL AWRE Aldermaston
Lt Col D B Williams, SMICR, AWRE Aldermaston
Mr D J Garrard, TL(C)1(N) MOD(PE) Castlewood House
Mr W N Saxby, DSC6 MOD London
Mr R Rankin, DSc6 MOD London.

There will be a speakers' rehearsal at RARDE at 2.0pm on Nov 29.

Yours ever

Bill.

W N SAXBY

Copy to:
Lt Col D W B Williams, AWRE Aldermaston
Major B J Burke " "
Mr E T Jenkins " "
Mr A D Greenhalgh " "

Col D Iles, RARDE Fort Halstead
Lt Col G G Carter, GS(OR)4

CONFIDENTIAL

CONFIDENTIAL

E29 | 1.

Marconi
Space and Defence Systems Limited

THE GROVE, WARREN LANE, STANMORE, MIDDLESEX
Telegrams: Electronics, Stanmore. Telex: 22616. Telephone: 01 954 2311

Your Ref:
Our Ref: PM/ST/M/L.9

Ext 212

Ministry of Defence,
D.S.C. 6,
Main Building,
Whitehall,
London, S.W.1.

March 19, 1971

Dear Sir,

We should be grateful to receive on loan a copy of the following report:-

M.O.D. Rept. Nuclear Weapons Effects Symposium
407/104/11/10

This document is required for work on Ministry of Defence Contract No. N/CP1128/70/EP689/DCP35 (2)

The engineer concerned is Mr. R.P. Murray.

Yours faithfully,

P.J. Malins

P.J. Malins (Miss)
LIBRARIAN

~~DJ~~ ~~[illegible]~~
~~R.A.~~ RA Supplied M,

Log

MINISTRY OF DEFENCE
D. Sc. 3
25 MAR 1971
FILE 104/~~12/30~~ 11/10

A GEC-Marconi Electronics Company L139

SECRET
UK EYES ONLY

Ref: 407/104/11/10

Copy No. 250 of 250 Copies

128 Pages

E28/1

Collated Papers Presented at the

# NUCLEAR WEAPON EFFECTS SYMPOSIUM

Held at Ministry of Defence, Main Building
Whitehall, London SW1
on
Friday 11 December 1970

**SECRET**

THIS DOCUMENT IS THE PROPERTY OF U.K. ATOMIC ENERGY AUTHORITY, and is intended only for the personal information of

____________________

____________________

and of those officers under him whose duties it affects. He is personally responsible for its safe custody and that its contents are disclosed to those officers and to them only.

The document will be kept under lock and key when not in actual use.

Ministry of Defence
D.Sc.6
Main Building, Whitehall
LONDON, SW1

SECRET
UK EYES ONLY

February 1971

Ref: 407/104/11/10

Page 1 of 128 Pages

Collated Papers Presented at the

# NUCLEAR WEAPON EFFECTS SYMPOSIUM

Held at Ministry of Defence, Main Building

Whitehall, London, SW1

on

Friday 11 December, 1970

Ministry of Defence
D Sc 6
Main Building
Whitehall
London, SW1

February 1971

## NUCLEAR WEAPON EFFECTS SYMPOSIUM 11 DECEMBER 1970

### CONTENTS

Page

INTRODUCTION

MILITARY ASPECTS

INTERNATIONAL ACTIVITIES

FACILITIES FOR EFFECTS WORK

PROGRAMME OF WORK

## INTRODUCTION

### Nuclear Weapon Effects and Target Response Work in the UK

Dr F H Panton (ACSA(N))

The object of this symposium is quite simple; it is to present to as wide a spectrum as possible of those interested people in MOD and other Departments - project leaders, policy makers, managers, designers and scientists - a broad brush account of the attack being made in the UK on nuclear weapon effects and the response of equipment to weapon effects. This is a further step along the road of, so to speak, normalization of weapon effect target response work, the end aim of which is to evolve a sufficient awareness and knowledge of nuclear weapon effects so that they may be taken account of in design of systems and equipment in a similar routine way as any other environmental effect. I think as an introduction to this symposium it would be best if I devoted the major part of the time allotted to me to an historical survey of the last four years' work.

Because it was uncertain about what should if anything be done about Nuclear Weapon Effects and Target Response, the WDC(NS) in its wisdom set up the WESG in 1966, and charged it with defining the nuclear environment in which the Services would wish to see their equipment survive, and with defining the means by which it could be ascertained whether equipment would survive in the environments specified. In 1968, the interim WESG report to the WDC(NS) provided services definitions of the nuclear environment and methodology for considering whether nuclear weapon effects needed to be taken into consideration. Not surprisingly, the different media in which the three Services operate produced different approaches to the problems, and lead to different constraints. Broadly speaking, the main Army concept in the context of the land battle in Europe is one which the equipment should only survive in conditions in which the men who operate it would survive for a reasonable period. The chief Air Force concept is that a sufficiently high percentage of a strike force of aircraft should be capable of attacking its targets after flying over a nuclear battle zone. The main Navy concept is that a ship's performance should not be catastrophically affected by the nuclear effects from a direct hit on another ship sailing at a specified distance away. Common to all three Services approaches is the concept of balanced hardening; that it doesn't make sense to, for instance, spend a lot of money on making equipment very hard to blast if the nuclear radiation associated with that blast level will inevitably cause the equipment to malfunction. Also in a sense common to all three approaches is the widespread EMP effect at surface level from high altitude bursts.

Well, with the basic approaches of the three Services to effects and nuclear environments defined, it was possible to begin studies of the possible responses of particular equipments to the environments specified, in order to get some feel for the seriousness or otherwise of the problems. Accordingly, in 1968 the WESG proposed, and WDC(NS) agreed, that the Services should nominate key equipments for AWRE (as the place where such expertise as existed in the UK lay to hand) to study and assess from the point of view of their vulnerability to nuclear environment, and to suggest how the equipments might be hardened to survive; WDC(NS) charged WESG with the co-ordination of this work, and with acting as the focal point in MOD for all weapon effects work. The object here was not necessarily so that these equipments should be hardened - that might be too expensive and difficult, and in any case, some of the equipment was obsolescent - but that we all might get a clearer idea of how to tackle that side of the problem. That programme is drawing to a close and has yielded some most useful and interesting results. In sum and very broadly, I think it has shown that while we may have nothing to fear with older valve equipment, transistorised and modern equipments may fail in environments specified.

As the chief system to attack we chose the Field Artillery Computer Equipment; with the assisstance of our American colleagues we have assessed it for TREE, and on our own we have looked at it for EMP effects. For the first time therefore we were able to predict the response of a UK equipment to radiation and EMP environments, and have been able to propose measures which would alleviate the damage caused. As a continuation of that exercise, one prototype FACE is being hardened to meet the specific environment.

Other army equipment, notably in the communication field, has been examined by AWRE and assessed for vulnerability to EMP and TREE and to Blast and Thermal effects. Mintech work at Boscombe Down has centred on exposing aircraft hulls in an EMP simulator, designed by AWRE, in order to ascertain the degree of attenuation of the EMP field provided by the hull. RAE through their Weapon Effects Panel has started a programme of investigation of coupling of EMP in vital electronic systems inside the aircraft, using the work at Boscombe Down as a point of departure. MRCA is an aircraft receiving attention in this context. Navy Department, with the advice of AWRE, has begun to look particularly at EMP effects in communication equipment at the specified levels.

All this work has enabled us broadly to see that although equipment we have looked at may fail, failures may not be too catastrophic and remedies may be possible, and in 1970, WESG was able to submit another report to WDC(NS), recommending, as a result of the work already done, that the Services should give serious consideration to the design phase to nuclear hardening, having due regard to cost and other factors. That recommendation was accepted, and appropriate words are now being inserted into staff requirements for new systems, and a start has been made, at least by the Army and the Air Force, to implement it. Again, assistance and advice is available to the Services from AWRE, with WESG in a co-ordinating role. In addition, since we must now look to integrated circuits rather than microminiaturised or transistorised circuits, a start has been made between AWRE, CVD, and the GEC Hirst Laboratories on pilot R&D looking to the design of hardened integrated circuits.

In all this work the WESG and the WDC(NS) realised that the UK would be wise to proceed as far as possible in concert with its NATO allies and the Americans. It would make little sense if we were to harden our equipment for use in a land battle in Europe, while allies on our flanks had taken no notice of nuclear weapon effects in their preparations. Accordingly, the UK has played a leading role in the QSTAG discussions which will most likely culminate this year in an agreed document on criteria for nuclear hardening, the philosophy of which owes much to the UK Army Department approach. In addition, similar discussions have begun in the wider NATO forum. Then there is TTCP Sub-Group N, under which we obtain a great deal of useful information and assistance from the US, and which, particularly in the blast field, has organized may fruitful joint experiments with the US and Canada.

Well, our programme today, as I said, is designed to give you a broad brush picture of the UK efforts in the target response weapon effects field and will include further details on most of the matters mentioned in my short introduction. To start the programme we thought it best to remind you of and update you on blast, thermal, radiation and EMP effects and then to give you an outline of the criteria for hardening developed by the Services for their equipment, and the methodology employed. There are presentations on co-operation on exchange with other contries through TTCP, QSTAG, and NATO forum. We shall attempt to summarize for you the progress of work at the establishments so far involved, that is AWRE, RAE, A&AEE, ASWE and NCRE. We shall describe briefly for you what training programmes have been organised, or are projected, under the aegis of D Sc 6. Somewhat as an extra, we have asked the Cabinet Office to tell us how they are tackling the problem of effects on National Communications and Power Supplies. There is a small exhibit of equipment and simulators in the room on my left.

If you have stayed the course (and if we are not by then in total darkness) there will be a short time for questions and discussion at the end of the afternoon. In case I don't find time at the end of the afternoon to summarise, let me now emphasise that we can obviously only today hope to show the surface problems. If any of you want to probe deeper, you have only to do so with the individual team, and more specifically with D Sc 6, whose task it is indeed to act as a focal point for MOD efforts in this field.
I will now ask Mr Greenhalgh of AWRE to open with a presentation on Weapon Outputs,

# GENERAL POSITION REPORT ON NUCLEAR WEAPON EFFECTS

A D Greenhalgh (AWRE)

## 1 Introduction

Nuclear Weapon outputs are well defined in Capabilities, DASA EM1 (previously known as TM-23-200), [Ref 1] and I don't propose to go over again the blast, thermal and radiation data. However, in order to apply the QSTAG (the Quadripartite Standardisation Agreement) on hardening - or better , the survivability - of military equipment, these outputs must be interpreted and used to define the environments that equipments may be exposed to.

The QSTAG, in its 3rd draft [Ref 2] is a document in process of agreement by the Armies of the four nations (US, UK, Canada and Australia) which sets out an approach to the problem of defining the survivability level for military equipment. You will be hearing more about this later. It is not a source book of nuclear data but it does give a brief exposition of the data on which its philosophy is based, and it is aspects of these which have not been widely disseminated before that I propose to deal with. As the QSTAG has not yet been ratified and as there is some divergence in outlook between the US and UK on certain nuances in interpretation, the information given now is not necessarily final. I will indicate the areas in which this divergence occurs, where the interpretation is still under discussion.

I should emphasise, however, that these grey areas do not in any way detract from the agreed hardening philosophy and the Army Dept. in the UK fully support the adoption of the draft QSTAG.

## 2 Thermal Radiation

The thermal output from a nuclear weapon is defined by:

$$Q = \frac{E\,W\,f\,T}{4\pi R^2}$$

Where Q is the total energy falling on a surface at a distance (slant range) R. When Q is in $cal/cm^2$
Then $E = 10^{12}$ calories
W is the yield in kilotons
f is 1/3 for low airbursts
and R is in metres
(for SI units, 1 cal = 4.19 Joules and 1 $Joule/mm^2 = 25\ cal/cm^2$ approx)

T is the transmissivity of the atmosphere and to take account of this causes some complications. Weather conditions in Northern Europe are very variable and do not necessarily conform with the conditions on which the data in DASA EM1 are based. If T is assumed to be unity, then we get a straight line on a log/log plot of Q versus range (see Figure 1). In the QSTAG, as in DASA EM1, T is calculated from an empirical relationship:

$$T = e^{-3.91\frac{R}{V}}\left(1 + 0.7\frac{R}{V}\right)$$

where V is the visibility.

Previously 10km has been assumed to be representative of Northern Europe. This has been felt to be a little unsatisfactory as the presence of clouds can significantly increase the thermal dose falling on a ground target (which can be allowed for in calculations by artificially making T greater than 1).

Early this year Major C Pritchett (then attached at AWRE) continued a study started earlier by Mr R Rankin of D Sc 6, of data provided by the meteorological office of the visibility and cloud cover for a number of airfields in West Germany over a number of years. Snow cover data were also studied [Ref 3].

Briefly, the frequencies of occurrence of various visibilities in various conditions of cloud cover were charted, from which it was possible to identify, with reasonable confidence, conditions not exceeded on 5% of occasions and these could define poor visibility at one end of the range and good visibility at the other end.

Poor visibility is broadly defined as about 1km. Transmission factors for conditions worse than this cannot be estimated with any confidence but their probability of occurrence throughout the year is low, Good conditions of thermal transmissivity, with enhancement, demand an overcast sky with cloud base between 300 - 1500m, together with clear atmosphere, visibility being above 25km. In average conditions, that is conditions obtaining 50% of the time, visibility is about 8km.

A number of methods of calculating transmissivity of the atmosphere were explored, that of Riley was chosen, mainly because other methods were not valid for poor visibility, and because Riley's formula allowed for the effect of cloud cover [Ref 4]. The results were adjusted to take account of the prevalence of snow cover on some occasions.

Figure 2 shows the variation of these calculated transmission factors with distances up to about 25km for conditions not exceeded in 5% (poor), 50% (average) and 95% (good) occasions. The enhancement of transmissivity in good conditions is well marked. No confidence limits can be set to the transmissivities. However, the meteorological data is adequate and a wider analysis is unlikely to change the results. Riley's formula is empirical, but it is the best that exists and the uncertainties are less when the formula is used to evaluate findings based on a large number of observations. Using these transmissivities, Q can be calculated. The graph of Q versus range for 1kton given in Figure 1 compares "poor" and "good" conditions with T = 1 and with the 10km visibility conditions as defined in the QSTAG.

As expected, for 1kton at short ranges the differences are not significant but as the ratios for higher yields are the same, for yields of 30kton upwards (where the thermal dose is multiplied by the weapon yield W) the enhancement arising from cloud cover causes a significantly higher thermal dose than in the average or poor visibility conditions, and this has to be taken into account when defining the survival criteria for equipments.

To apply the above to the derivation of criteria for the hardening of military equipment, the following ground rules would be recommended when there is a limiting thermal condition:-

a Blast and radiation criteria should be derived from the envelope of the three curves defining:

The blast limiting condition
The radiation limiting condition
The thermal limiting condition <u>when transmissivity is poor</u>

b As it is relatively easy to harden against thermal effects, thermal criteria should be derived from the envelope of the three lines defining:

The blast limiting condition
The radiation limiting condition
The thermal limiting condition <u>when transmissivity is good</u>

In cases where there is no thermal limiting condition, thermal criteria derived from other limiting conditions should be calculated using factors appropriate to <u>good transmissivity</u>.

## Thermal Pulse

The shape of the thermal pulse is also important as materials with a low heat capacity or which lose or conduct heat away only slowly are likely to be more vulnerable to pulses of high delivery rate. Any estimations made of the response of equipments to thermal stress should take account of the dynamic nature of the phenomena. For low yield weapons the thermal energy is delivered in a short time, as measured by the time to 2nd maximum (Figure 3). (The first maximum contains very little energy and can be ignored.)

The time scales with yield (W) according to:

$$T_{max} = 0.043W^{0.43}$$

thus for $W = 1\text{kton}$ $T_{max} = 0.043\text{sec}$

$W = 10\text{kton}$ $T_{max} = 0.116\text{sec}$

$W = 100\text{kton}$ $T_{max} = 0.312\text{sec}$

$W = 1000\text{kton}$ $T_{max} = 0.84\text{sec}$

There is still a little uncertainty about the total pulse length, the US handbooks (DASA EM1 and the QSTAG) favouring 80% of the energy delivered in $10T_{max}$, whereas other US sources and the UK favour a sharper pulse, say 80% in $3T_{max}$ and 100% in $10T_{max}$. It is understood that DASA EM1 is to be amended in due course, but the exact figures will have to await the issue of the amendment.

## 3 Neutron and Gamma Radiation

Here, I am only going to be concerned with the initial radiation from the bomb, and not any effects of residual radiation due to fall-out and/or neutron capture.

Although these radiations obey an inverse square law initially, because of absorption and scattering in the atmosphere the intensity tends to fall off more rapidly with increasing range. Furthermore, the energy of the radiations diminishes or softens by atmospheric scattering. The effect of these radiations is also a function of degree of absorption in the materials of interest, as well as of their intrinsic energy. The radiation dose that describes this is the Rad, defined as the absorption of 100 ergs of energy per gram of material.

The data given in DASA EM1 is for "tissue" equivalent material, that is soft tissue, ie personnel. Because the absorption of radiation by the different tissues of men (bones versus nerves versus fat etc) varies, the detailed study of these effects tends to be somewhat complicated. However, there are so many other uncertainties in the military field (yield, range, terrain effects and variation in output), that in general, little is lost in accuracy, and a great deal gained in simplicity by ignoring the fine detail and working in absorbed Rad (tissue) of 1MeV equivalent. For a fission neutron spectrum:

$$1\text{n/cm}^2 = 1.8 \times 10^{-9} \text{ Rad (tissue)} \ldots\ldots \text{(QSTAG)}$$

For the semi-conductor devices in modern electronic equipment, it is the total neutron dose which is significant, rather than dose-rate. For $\gamma$ radiation however, it is the ionising effect which is damaging and, because of recombination, this is time dependant. Hence the dose-rate is important. $\gamma$ dose-rate values have been agreed between the US and UK and these are given in the latest version of the draft QSTAG, and shown in Figure 4.

### Shielding

The neutron and gamma radiation falling on equipment can be attenuated by heavy armour if the equipment is inside a tank - or conversely, if the operator is protected by being inside a slit trench or armoured vehicle, the equipment (which may be unprotected) will be required to withstand a higher intensity of radiation.

The QSTAG proposes two types of shielding:

a Lightly armoured vehicles, APC's etc - Transmission factor of 0.9

b Heavily armoured vehicles, slit trenches - Transmission factors of 0.2 for gamma and 0.3 for neutrons.

These factors are somewhat arbitrary depending on the particular construction and the position of the man inside and, as in any case the dose-rate changes quite rapidly with yield and range, the UK would propose a further simplification giving only transmission factors of:

1 for all vehicles
0.3 for heavily armoured tanks and slit trenches
0.1 for heavily protected command posts,

these transmission factors applying to both neutron and gamma radiation.

### 4 Blast

Against blast, military equipment is generally considered to be a drag type target, sensitive to the drag forces associated with dynamic pressure and its duration, as well as to static overpressure and its duration. The response of equipment is governed by some combination of these pressures. The maximum values of static overpressure and dynamic pressure at which such targets fail, occur at the minimum yield while the maximum values of positive phase duration and overpressure impulse occur at the maximum yield.

In the QSTAG the US therefore specify two sets of values of the following parameters:

static overpressure
dynamic pressure
positive phase duration
positive overpressure impulse

that equipment must withstand. (see Figure 5)

In view of the scanty nature of the data available for the calculation of dynamic pressure impulse, the UK have suggested that a quantity termed the QTI (the product of the peak dynamic pressure and positive phase overpressure duration) be adopted as a suitable criteria. The QTI can be used to obtain estimates of the velocity (V) acquired by a drag target using the relation:

$$V = k \times QTI \times C_d \times \frac{A}{M}$$

where $C_d$ is the drag coefficient
A is the area presented by the target normal to the blast wave
M is the mass of the target
k is a wave shape factor, of about 0.4 in clean air and up to about 1 in full precursor conditions (0.4 would seem appropriate to North West Europe)

Last year, AWRE issued a paper discussing the blast vulnerability of Box Body Trucks used for BRUIN signals equipment [Ref 5]. It was shown that the ranges at which these vehicles will just overturn were very close to the 50% moderate damage to wheeled vehicles curve in the QSTAG (see Figure 6). The point is that although the vehicles themselves will probably still be serviceable (or quickly made so when righted) the electrical equipment they carry might be severely damaged.

## 5 EMP

A detailed account of EMP was given at the last symposium by Mr Siddons of AWRE

To recap briefly, there are two distinct situations:

a The low airburst of tactical weapons (say up to 200kton)

b The high altitude exo-atmospheric case in which a megaton range weapon is exploded above (or well above) 35km altitude.

In (a) the EMP pulse can vary quite markedly with range, but not very much with yield.

In (b) the field strength is practically independent of range over several hundred km from ground zero, but does depend on the angle between the line of sight and the geomagnetic field direction, with a maximum when this angle is about 45°. Again, the field strength is not very yield dependant.

To cover both the above cases, the US in the draft QSTAG recommended a generalised pulse shape as being representative of the more severe levels that would be encountered (see Figure 7). The UK believes that, in the present state of our knowledge of equipment response to EMP, it would be useful to consider wave forms more closely related to particular circumstances than can be expressed by a single composite pulse.

A lot of work is going on at the moment at AWRE, in assessing recent information on the ground/low airburst EMP wave shape and amplitude, at various ranges from various weapon yields. It is hoped that this will be published shortly.

Figure 8 shows two curves, one of a typical low airburst/groundburst, the other a typical exo-atmospheric burst.

These are only illustrations. It may well be desirable for the purposes of equipment hardening and survivability studies to adopt model shapes of pulse for various postulated situations, this would have the merit of preventing confusion between different establishments working in this field.

REFERENCES

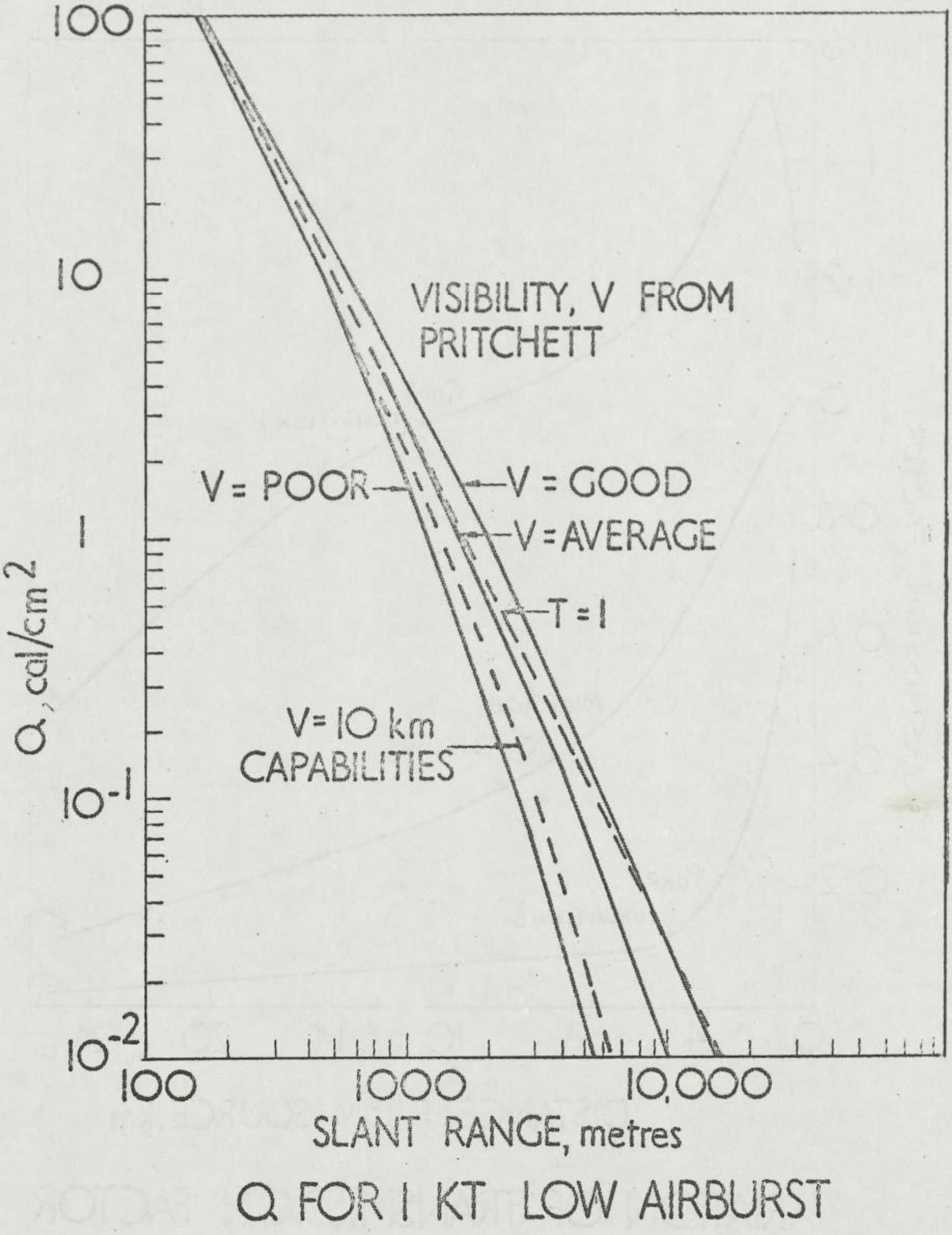
1 Capabilities of Nuclear Weapons, DASA EM1 dated 1.1.68 (Confidential)

2 Criteria for Hardening Equipment against Nuclear Weapon Effects, Draft QSTAG, March 1970. (ABCA Armies Standardization Programme) (Confidential)

3 Thermal Transmission Factors for Use in Military Studies, Major C Pritchett, SMR Tech Memo No 1/70 ref: AWRE/ARMY/R2/4 dated June 1970 (Restricted)

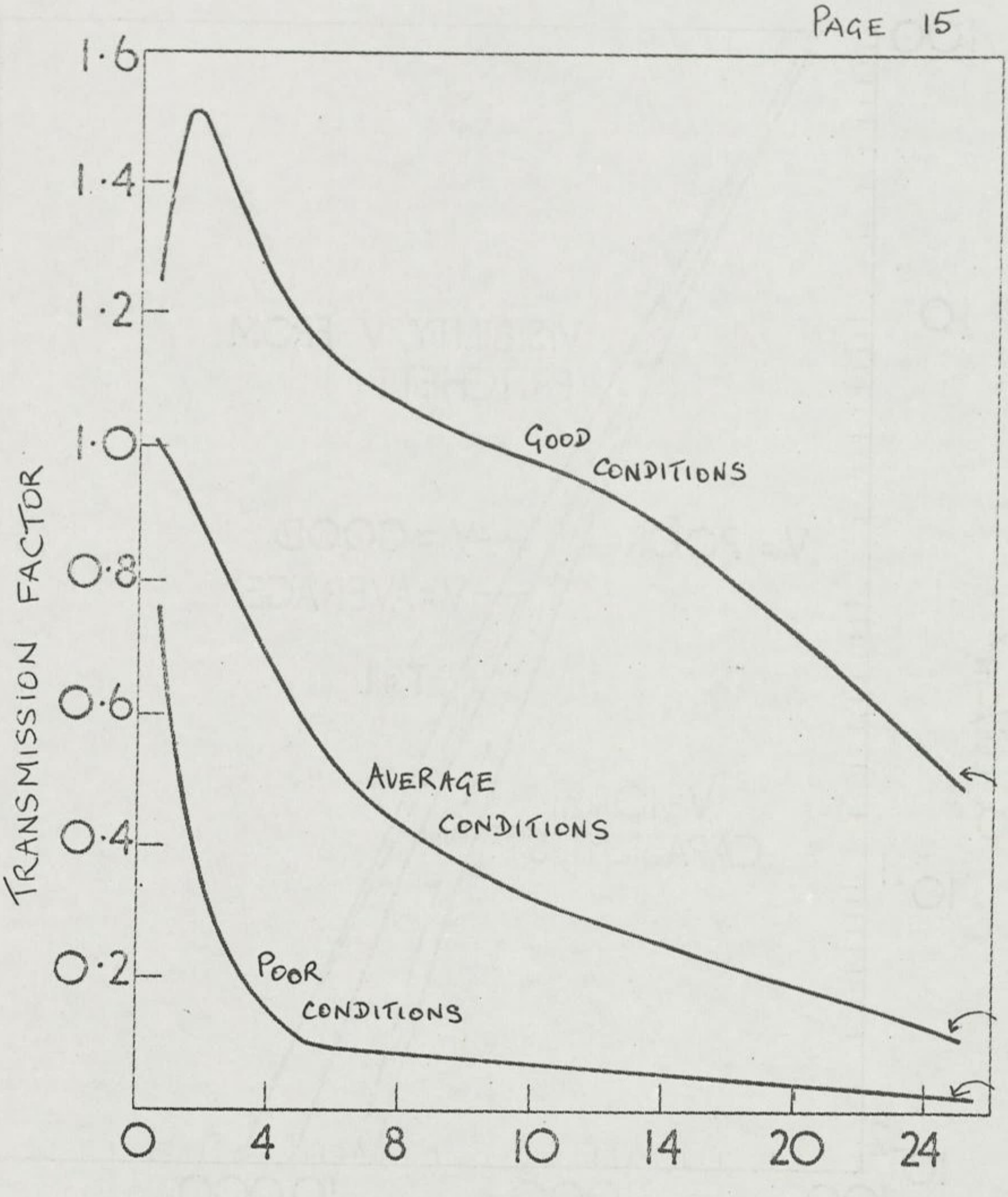
4 G F Riley: Empirical Determination of Scattered Light Transport through the Lower Atmosphere. AFCRL-68-0256 dated May 1968

5 The Vulnerability to Air Blast of Army Communication Equipment Carried in Box Body Trucks - J M Jarvis, R D Rowe and A V Smith of AWRE ref: WECC/P/32 dated October 1969



Q FOR 1 KT LOW AIRBURST

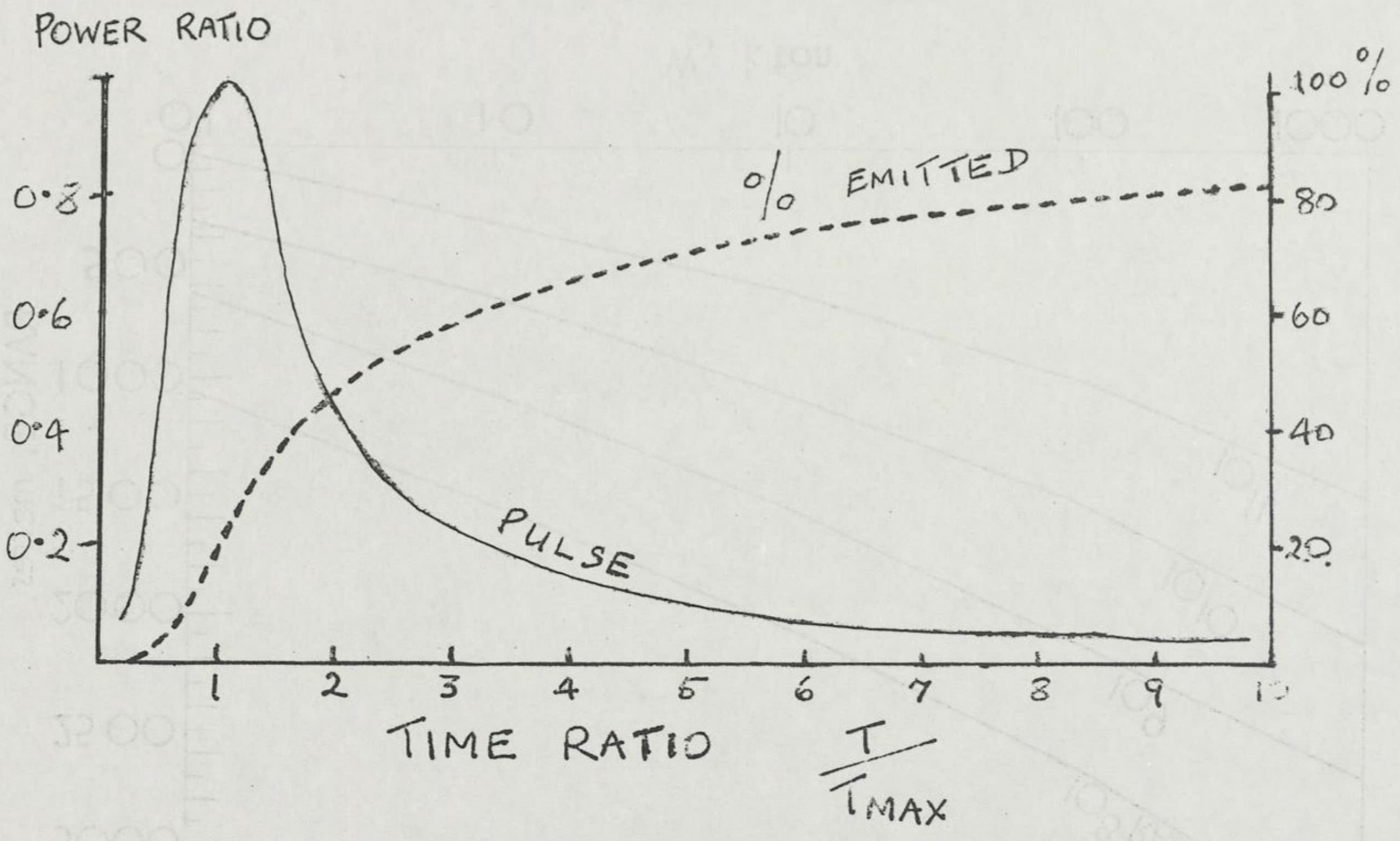
FIGURE 1



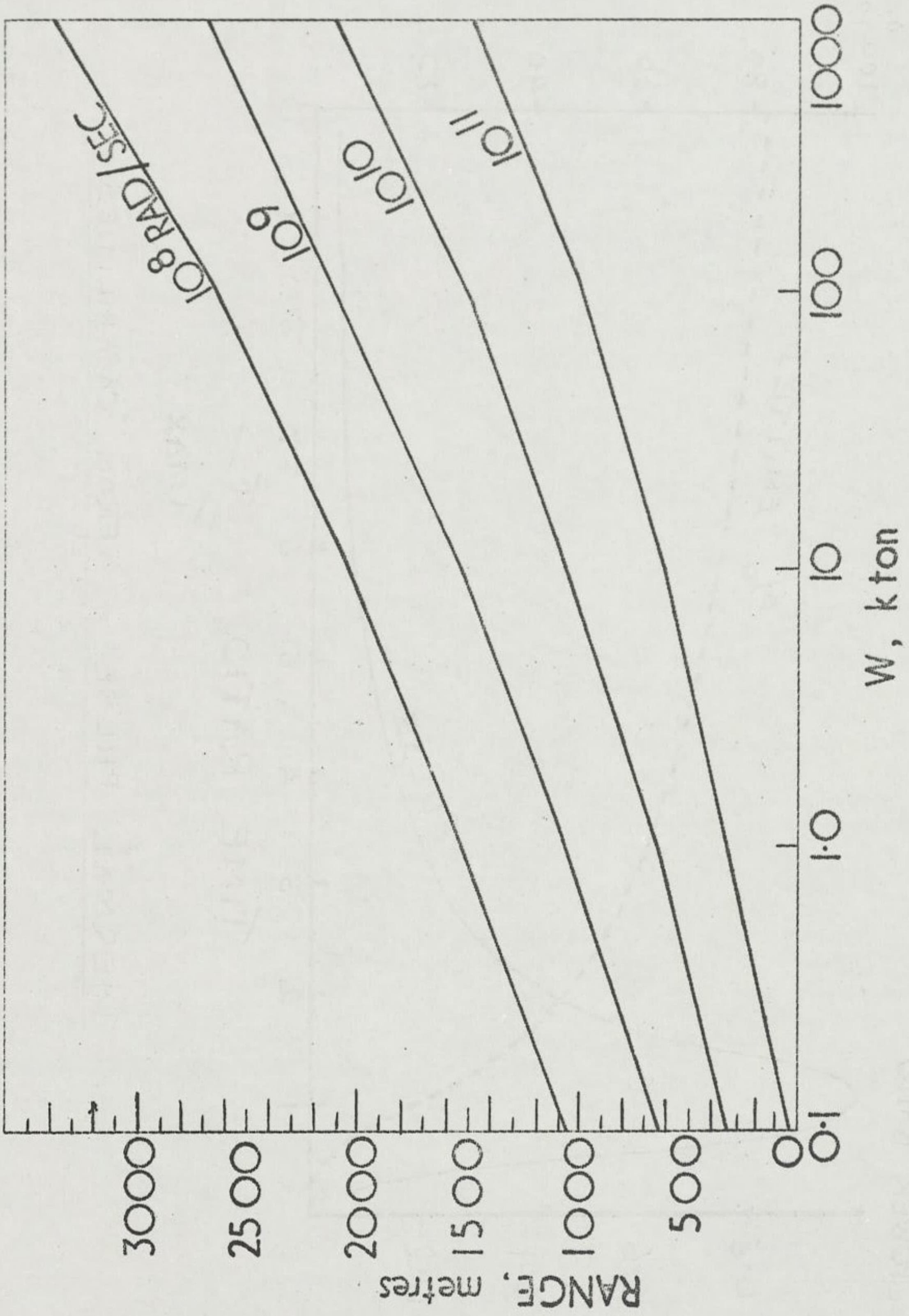
VARIATION OF TRANSMISSION FACTOR WITH DISTANCE

FIGURE 2

FIGURE 3



THERMAL PULSE - FROM "CAPABILITIES"



MAX γ DOSE-RATE

FIGURE 4

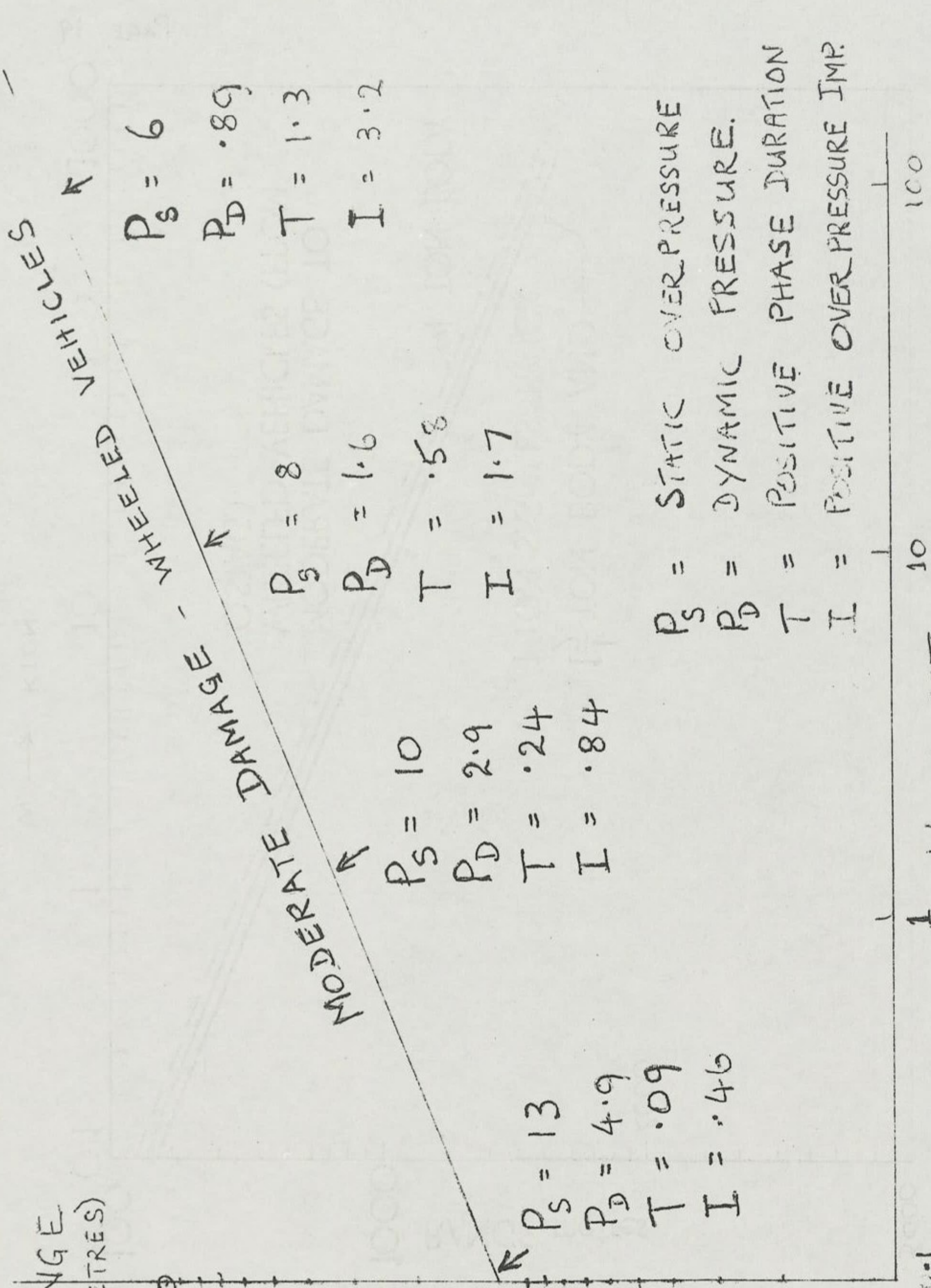

RANGE (METRES)
1000
100
0·1
1
10
100
W → KT
MODERATE DAMAGE - WHEELED VEHICLES
PS = 13
PD = 4·9
T = ·09
I = ·46
PS = 10
PD = 2·9
T = ·24
I = ·84
PS = 8
PD = 1·6
T = ·58
I = 1·7
PS = 6
PD = ·89
T = 1·3
I = 3·2
PS = STATIC OVER PRESSURE
PD = DYNAMIC PRESSURE.
T = POSITIVE PHASE DURATION
I = POSITIVE OVER PRESSURE IMP.

FIGURE 5

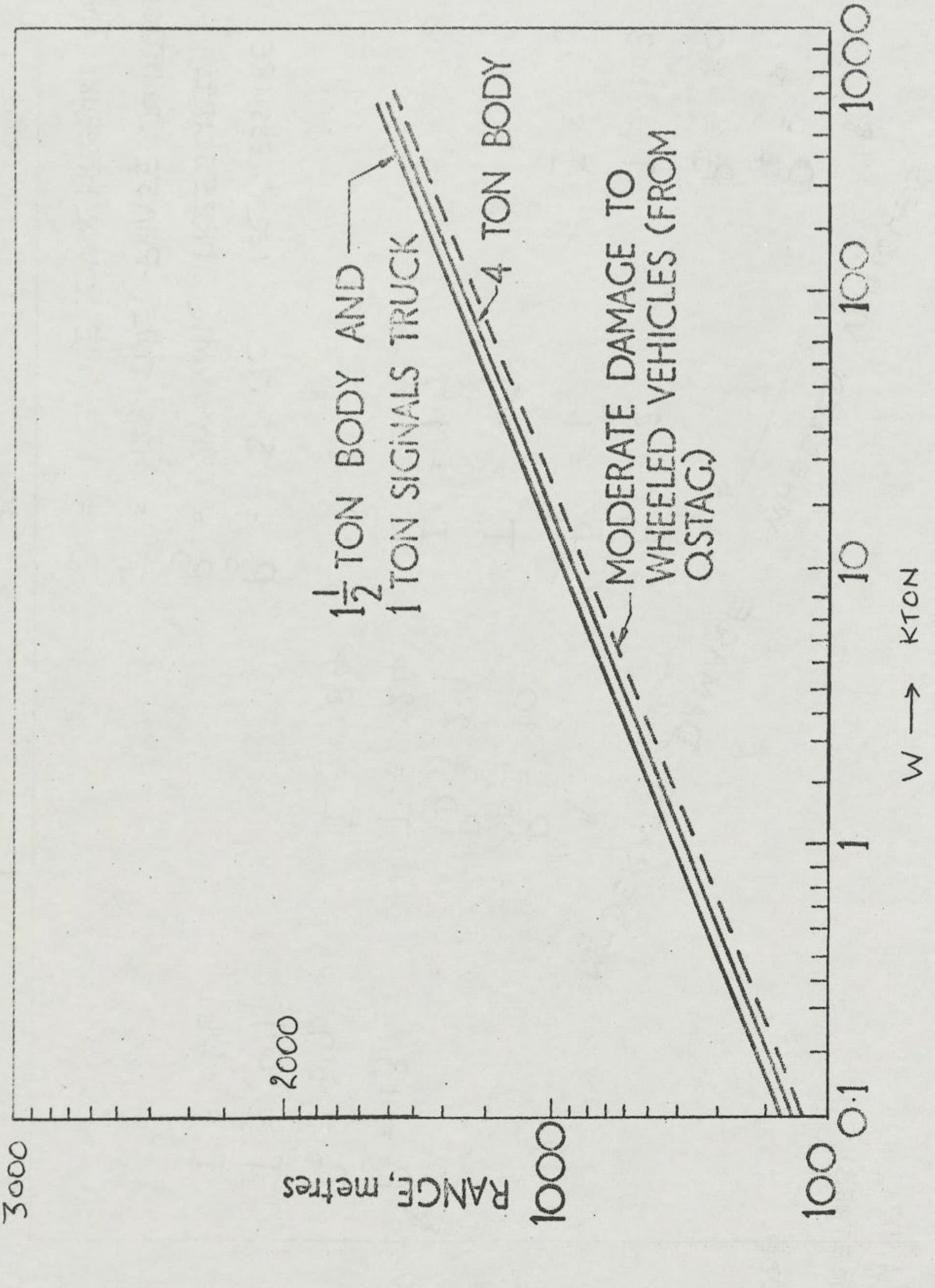
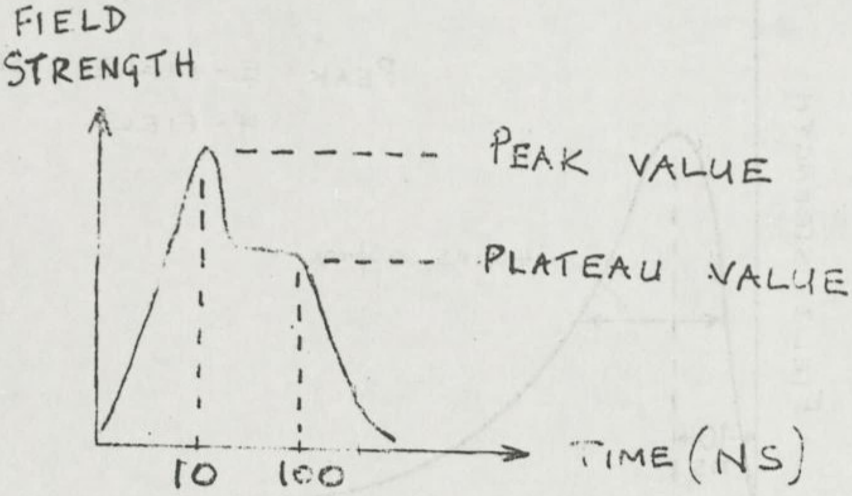

RANGE, metres
3000
2000
1000
100
0·1
1
10
100
1000
W → KTON
$1\frac{1}{2}$ TON BODY AND
1 TON SIGNALS TRUCK
4 TON BODY
MODERATE DAMAGE TO
WHEELED VEHICLES (FROM
QSTAG)

FIGURE 6



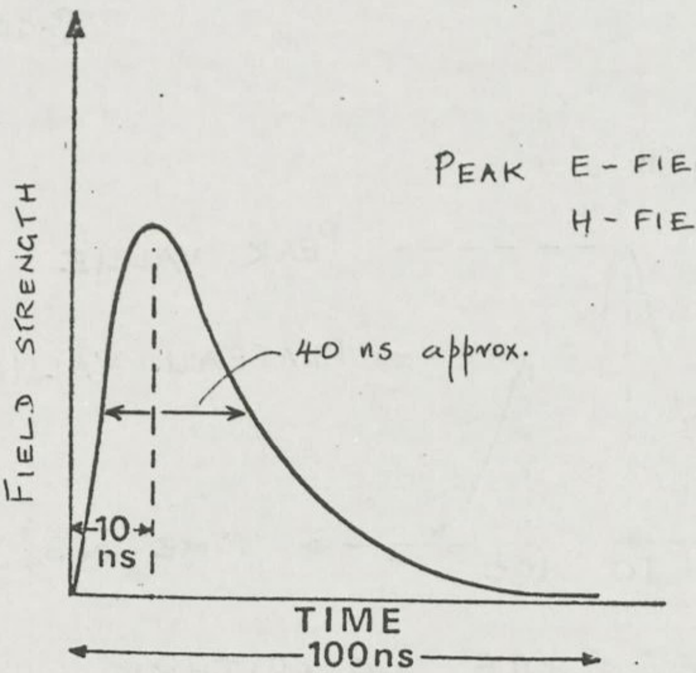
BOTH SCALES ARE LOGARITHMIC

TYPICAL VALUES:

| | |
|---|---|
| PEAK ELECTRIC FIELD | 50 kV/METRE |
| PEAK MAGNETIC FIELD | 900 Amp/METRE |
| PLATEAU E FIELD | 1 kV/METRE |
| PLATEAU H FIELD | 230 Amp/METRE |
| OVERALL PULSE DURATION | 5 MICRO SEC |
| POLARISATION | RANDOM. |

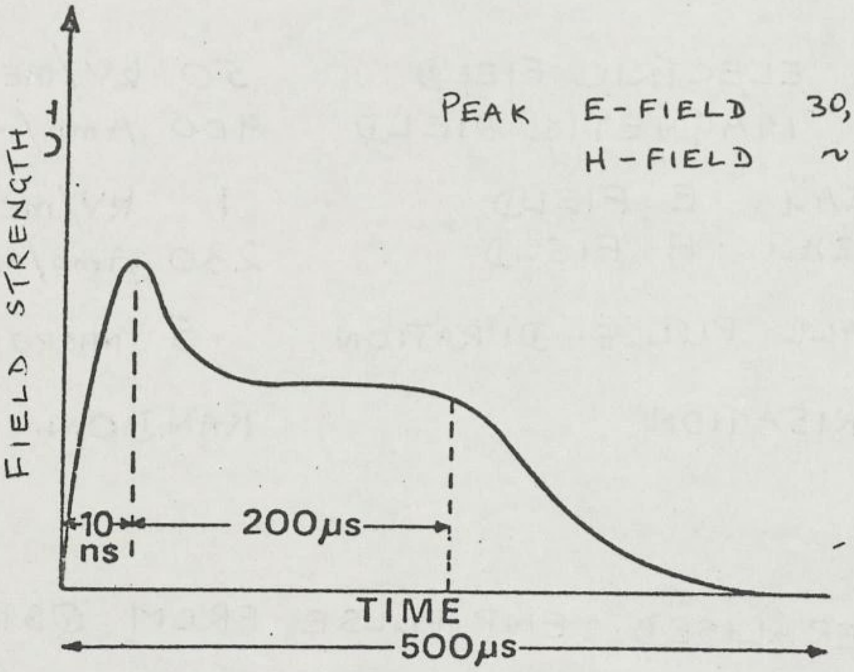
GENERALISED EMP PULSE FROM QSTAG

FIGURE 7



PEAK E-FIELD 50,000 V/m
H-FIELD 130 A/m

EXO—ATMOSPHERIC PULSE



PEAK E-FIELD 30,000 V/m
H-FIELD ~ 80 A/m

GROUND / LOW AIR BURST PULSE

The 10 ns RISE TIME IS FROM 10% to 90% PEAK HEIGHT IN BOTH CASES

FIGURE 8

## MILITARY ASPECTS

### Navy Department - Nuclear Weapon Effects

Cdr H Thompson (MOD(N))

## THE THREAT

1 The Royal Navy has the good fortune to carry out its business in mobile shelters. For over 20 years we have constructed our ships to offer the best possible protection to personnel from radiation hazards. Measures include sending the ship's company to shelter stations as deep down in the ship as possible, pre-wetting all the exposed surfaces of the ship to wash off particulate contamination, provision of an air-tight pressurised citadel which can be supplied with filtered air. Much has therefore been done to protect personnel. We will now take a look at the situation with regard to equipment.

2 First of all let us consider the threat in the maritime situation. I wish to postulate 4 possibilities for the use of nuclear weapons against our ships:

a Air burst nuclear weapons against our Task Force, Convoy or Amphibious operation

b Low Yield nuclear tipped torpedoes

c Our own or the enemy's nuclear depth bombs

d Exo-atmospheric nuclear burst

3 It is considered that surface ships would be exposed to attack by means of ship, submarine or air-launched cruise-missiles, delivered at long range and fitted with terminal homing. Nuclear warheads would most probably be within the range 5-20 kton, although the use of higher yield megaton warheads cannot be dismissed.

4 Submarine launched nuclear tipped torpedoes are unlikely to be of higher yield than 5-20 kton in order to avoid self-damage to the delivery vessel.

5 Free falling bombs are not considered a likely form of attack against ship targets.

6 Under the threat of nuclear attack, ships are deployed at separation distances of between one to five nautical miles depending on the force commander's assessment of the yield of weapon expected. However, this may not always be geographically or tactically possible, such as when ships are operating in restricted waters.

7 Constraints are necessary in the employment of our own Anti-Submarine nuclear depth bobms by both the parent surface ship and the helicopter to avoid self-damage due to underwater shock or involvement with the radio-active base-surge cloud.

8 Finally we are faced with the threat of an exo-atmospheric burst which, because of the resulting electromagnetic pulse, could result in damage to unprotected electronic or electrical equipment.

## ASSESSMENT

### Low Air Burst

9 Assuming high accuracy in weapon delivery, the critical environment in the case of ships deployed to withstand nuclear attack is equivalent to the weapon effects received at a range equal to the appropriate ship separation distance. Thus for a kiloton attack where separation is 1 nautical mile, and allowing for a circular error of probability of a few hundred feet, it is reasonable to assume a minimum ship to weapon distance of 1800 yards as a basis for the calculation of the critical environment.

10 Referring to Table 1, you will see that the peak overpressure in this case is 3.5 psi. The electromagnetic pulse is 5 kilovolts per metre.

11 Table 1 also shows the values that could be expected from a megaton weapon at distances of 3 and 5 nm. To restrict the blast peak overpressure to 3.5 psi in this case, it would be necessary for ships to be separated by 7 nm.

12 Before considering the other columns in the Table I would like to turn to the criteria from which they are derived. It is considered unnecessary to protect equipment from environments where members of the crew, in lightly protected positions would receive radiation doses in excess of 3000 rad. The choice of 3000 rad represents a dose level which, although ultimately fatal, is not immediately incapacitating and ensures a continued fighting capability after attack for a limited period which may be important tactically.

13 The radiation dose to men in lightly protected positions assumes transmission factors of 0.85 and 0.4 for neutron and gamma radiation respectively.

14 The first critical curve (Figure 1) shows the variation in range with yield for an overpressure of 3.5 psi. Also shown is the 3000 rad dose line. The range out to which digital circuits are likely to be affected due to initial gamma radiation is indicated. The right hand scale shows the estimate of the distance at which an EMP of 1 kV/m is received. It will be noted that all the curve for 3.5 psi falls to the right of the 3000 rad line and this curve therefore encloses the fighting capability envelope.

15 Figure 2 gives the curve for a blast overpressure of 10 psi and here you will notice that the curve starts to the left of the 3000 rad line and crosses it. The ship survival envelope in this case is composed of the 3000 rad line before cross-over and thereafter by the 10 psi curve, since our criterion is that personnel cannot withstand a radiation dose greater than 3000.

16 To achieve a balanced design, equipment must withstand the maximum values of weapon effects received at any position along the hatched envelopes indicated in the two figures.

17 Returning now to Table 1 you can see the critical environments for a balanced design assuming a blast overpressure of 3.5, 5 and 10 psi, or a radiation dose to lightly protected personnel of 3000 rad, according to whichever parameter predominates.

## Surface Bursts

18 In the case of a surface or shallow underwater burst resulting from a direct hit or a near miss by a cruise missile or a nuclear tipped torpedo, there will be the additional hazard of radio-active fall-out. This may necessitate the command ordering measures to avoid exposing personnel to high radiation doses, but the critical environment will not exceed that given for a low air burst.

## Underwater Bursts

19 Underwater nuclear bursts will produce the following environments:

a Underwater shock - affecting ships and submarines

b Base surge - affecting ships

c Surface waves - also affecting ships

The size of weapon is likely to be in the kiloton range and it is probable that it would be used at medium to deep depths where shock effects are the predominant factor.

20 Critical distances for various degrees of shock damage and for safe delivery of a 10 kton weapon at 5 depths of burst are shown in Table 3 for surface ships.

21 Similarly, Table 5 gives the critical distances for submarines. These distances can be used to assess both the safe delivery distances for a nuclear tipped torpedo and the distances at which various categories of damage will be inflicted on a submarine by depth bombs.

22 It will be appreciated that these tables are approximate in that all ships, even of one class, are not equally shock resistant. Also they do not take into account refraction and bottom reflection effects which could modify the ranges at which a particular level of damage is received.

23 Table 4 shows the radii of Base Surge for 4 depths of burst.

24 Surface waves from a 10 kton weapon are not considered to be a hazard.

## High Altitude Bursts

25 High altitude bursts, at heights in excess of 50 km, can also produce large electric fields at the earth's surface. A field of the order of 25 kV/m can be received at several hundred miles from surface zero. Table 2 shows the critical values for the pulse characteristics which could be expected.

## HARDNESS LEVELS RECOMMENDED

26 Radar aerials and other equipment sited outside the ship should be designed to withstand a blast overpressure of 3.5 psi. It is not reasonable to design equipment to withstand a greater blast overpressure for reasons of size, top-weight and economy. It follows therefore that electrical and electronic equipment should be hardened to withstand the Transient Radiation Effect and the Electromagnetic Pulse corresponding to a blast overpressure of 3.5 psi. This was the balanced design shown in Figure 1.

27 ACNS(OR) has directed that the cost of protecting equipment against EMP shall be studied for new equipments designed for the Royal Navy. To this end, the Material Departments have been consulted and are attempting to estimate the cost of hardening certain new equipments. One difficulty with which we are faced, however, is estimating the hardness required for equipment fitted in ships and, indeed, in a maritime environment. You will hear details of some of this work later.

SECRET

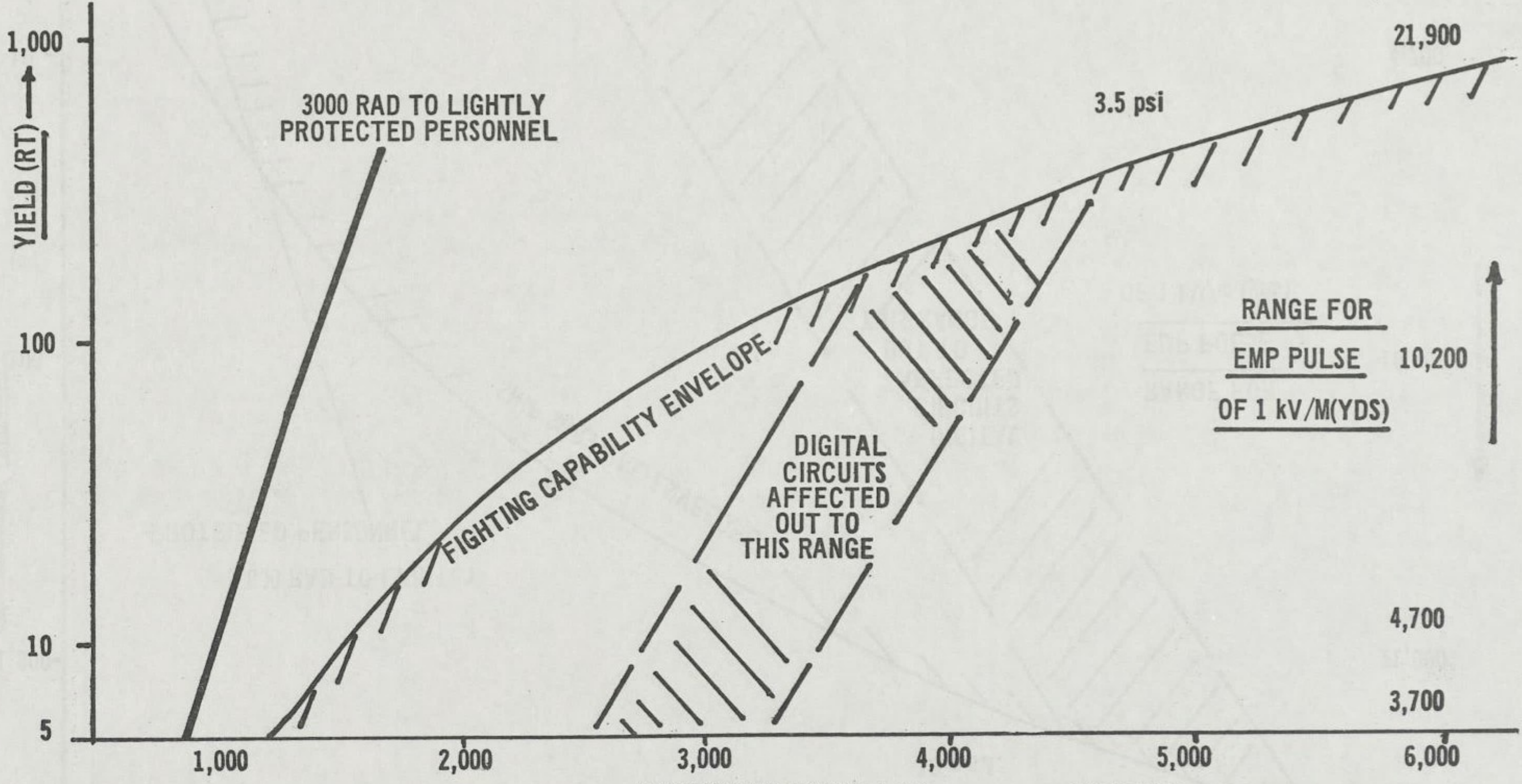


FIGURE 1 - CRITICAL CURVES - (Bi)

SECRET

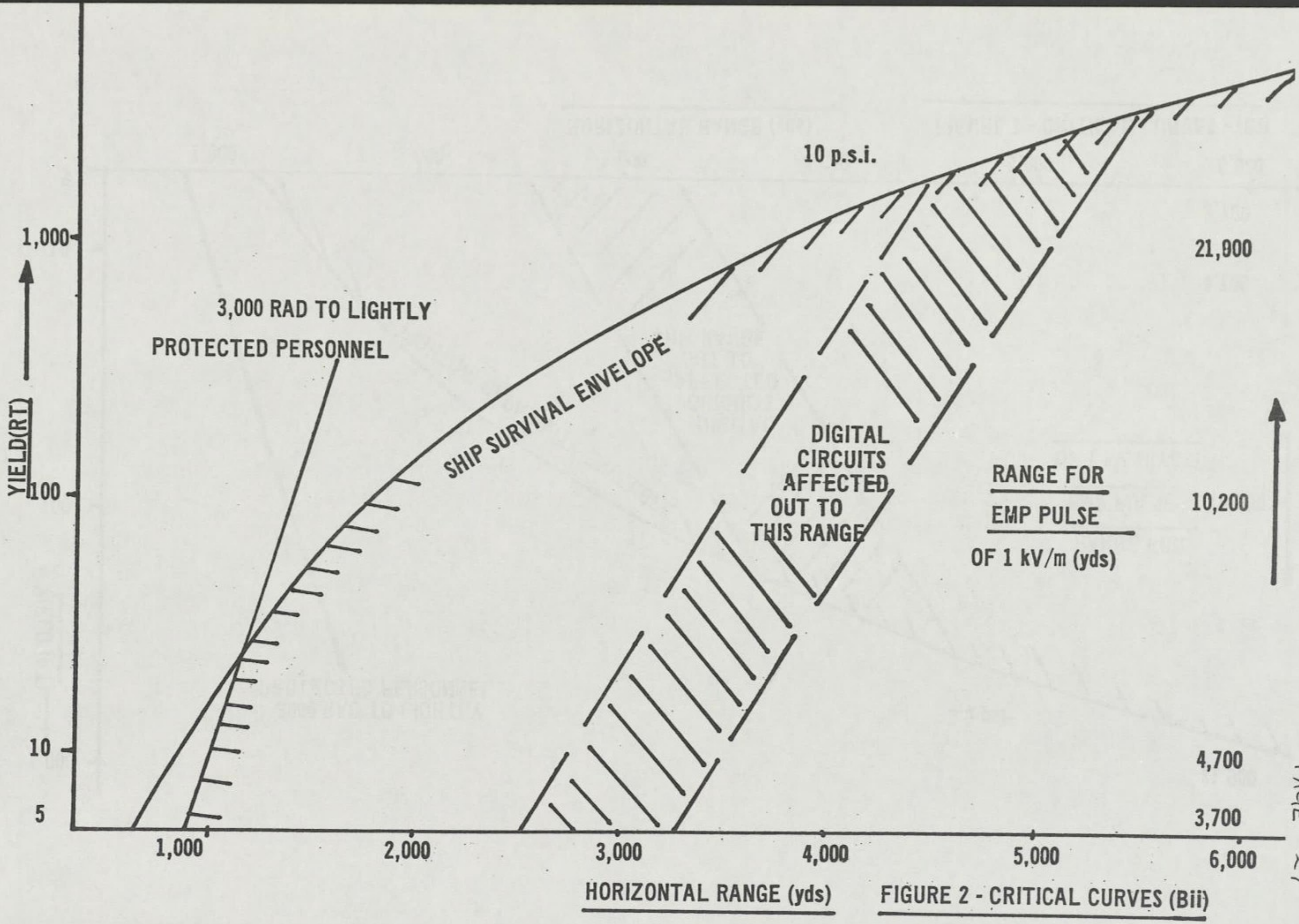


FIGURE 2 - CRITICAL CURVES (Bii)

## TABLE 1 CRITICAL NAVAL NUCLEAR ENVIRONMENTS

| | NUCLEAR DISPOSITION | | | BALANCED DESIGN | | |
|---|---|---|---|---|---|---|
| | KILOTON YIELD (20KT) | MEGATON YIELD (10MT) | | SHIPS HARDENED TO WITHSTAND | | |
| | 1800 yds | 3nm | 5nm | 3.5 psi | 5 psi | 10 psi ** |
| | Case A(i) | Case A(ii) | | Case B(i) | Case B(iii) | Case B(ii) |
| 1. PEAKE OVERPRESSURE - PSI | 3.5 | 15 | 6.4 | 3.5 | 5 | 10 |
| 2. PEAK DYNAMIC PRESSURE - PSI | $<1.0$ | 6.3 | 0.9 | $<1.0$ | $<1.0$ | 2.5 |
| 3. PEAK OVERPRESSURE IMPULSE - PSI - SECS | 1.4 | 22.6 | 15 | 11.5 | 13.4 | 18 |
| 4. DURATION OF POSITIVE OVERPRESSURE - SECS | 1.0 | 4.2 | 6.2 | 7.8 | 6.9 | 5.3 |
| 5. THERMAL FLUX - CALS/CM$^2$ | 18.0 | 480 | 150 | 70 | 110 | 240 |
| 6. TIME TO SECOND THERMAL PEAK - SECS | 0.14 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 |
| 7. NEUTRON DOSE - RADS * | 40 | NIL | NIL | 480 | 1700 | 2500 |
| 8. GAMMA DOSE - RADS * | 31 | NIL | NIL | 130 | 340 | 730 |
| 9. NEUTRON FLUENCE - N/CM$^2$ | $3\times10^{10}$ | $<10^{10}$ | $<10^{10}$ | $4\times10^{11}$ | $1.9\times10^{12}$ | $3\times10^{12}$ |
| 10. ELECTROMAGNETIC PULSE (EMP) | | | | | | |
| a. PEAK ELECTRIC FIELD (EP) - kV/m | 5 | 15 | 4 | 9 | 14 | 17 |
| b. PEAK MAGNETIC FIELD (HP) - AMP/M | 13 | 45 | - | 18 | 160 | 350 |
| c. RATE OF RISE OF MAGNETIC FIELD (HP) - AMP/M/SEC | $4\times10^{7}$ | $2\times10^{8}$ | - | $6\times10^{7}$ | $8\times10^{9}$ | $1.3\times10^{10}$ |
| d. RISE TIME - $\mu$ SECS | 0.3 | 0.2 | - | 0.3 | 0.02 | 0.02 |
| e. PLATEAU ELECTRIC FIELD (EPL) - kV/M | 3 | 9 | - | 6 | 8 | 17 |
| f. PLATEAU MAGNETIC FIELD (HPL) - AMP/M | 13 | 20 | - | 54 | 90 | 80 |
| g. DURATION OF PLATEAU - $\mu$ SECS | 30 | 70 | - | 40 | 70 | 100 |
| 11. GAMMA DOSE - RATE - RAD/SEC | $10^{8}$ | NIL | NIL | $1.9\times10^{9}$ | $5.4\times10^{9}$ | $7.1\times10^{9}$ |

* IN PROTECTED POSITIONS

** MAXIMUM VALUE CORRESPONDING TO 10 PSI OR 3,000 RAD TO PROTECTED PERSONNEL

## TABLE 2

## SURFACE EMP FIELDS FROM AN EXO-ATMOSPHERIC NUCLEAR EXPLOSION

| PULSE CHARACTERISTIC | CRITICAL VALUE |
|---|---|
| 1. PEAK ELECTRIC FIELD (EP) | 50 KV/M |
| 2. PEAK MAGNETIC FIELD (HP) | 150 AMP/M |
| 3. RATE OF RISE OF MAGNETIC FIELD ($\dot{H}$) | 1.5 X $10^{10}$/AMP/M SEC |
| 4. RISE TIME | 10 NONOSECS |
| 5. HALF WIDTH | 10'S OF NONOSECS |
| 6. TAIL | 100 NONOSECS |

## TABLE 3

## DAMAGE RANGES AND SAFE DELIVERY DISTANCES

## SURFACE SHIPS - 10 KT WEAPON

| DEPTH OF BURST (FEET) | HORIZONTAL RANGE (YARDS) | | | |
|---|---|---|---|---|
| | SHOCK LEVEL | | | |
| | SEVERE | MODERATE | LIGHT | SAFE DELIVERY |
| 100 | 200 | 300 | 450 | 900 |
| 250 | 350 | 500 | 800 | 1500 |
| 500 | 500 | 800 | 1200 | 2300 |
| 1000 | 800 | 1200 | 1800 | 3200 |
| 2000 | 1100 | 1600 | 2300 | 4300 |

## TABLE 4

## SPREAD OF BASE SURGE FROM A 10 KT WEAPON (NO WIND)

| DEPTH OF BURST (FEET) | RADIUS OF BASE SURGE (YARDS) | | |
|---|---|---|---|
| | 20 SECONDS | 60 SECONDS | 120 SECONDS |
| 300 | 740 | 1700 | 2500 |
| 500 | 670 | 1600 | 2200 |
| 1000 | 570 | 1400 | 1700 |
| 2000 | 500 | 1200 | 1400 |

## TABLE 5

## DAMAGE RANGES AND SAFE DELIVERY DISTANCES

## SUBMARINES - 10 kT WEAPON (BEAM EXPOSURE)

| OPERATING DEPTH | DEPTH OF BURST (FEET) | DEPTH OF SUBMARINE (FEET) | HORIZONTAL RANGE (YARDS) | | | |
|---|---|---|---|---|---|---|
| | | | SHOCK LEVEL | | | SAFE DELIVERY |
| | | | SEVERE | MODERATE | LIGHT | |
| ALL VALUES | 100 | 50 | 450 | 550 | 800 | 1200 |
| | | > 400 | 1000 | 2100 | 5000 | 10000 |
| | 250 | 50 | 700 | 850 | 1300 | 1900 |
| | | > 400 | 1000 | 2100 | 5000 | 10000 |
| | 500 | 50 | 900 | 1300 | 2000 | 3100 |
| | | > 400 | 1100 | 2200 | 5100 | 10000 |
| | 1000 | 50 | 1200 | 1800 | 2800 | 4300 |
| | | > 400 | 1300 | 2300 | 5100 | 10000 |
| | 2000 | 50 | 1400 | 2300 | 4000 | 6000 |
| | | ≳ 400 | 1400 | 2300 | 5200 | 10000 |

## MILITARY ASPECTS

### Army Department - The Hardening of Army Equipment Against Nuclear Weapon Effects

Lt Col D W B Williams (AWRE/Army)

### Aim

1. The aim of this talk is to introduce the subject of Nuclear Hardening in general terms mainly for the benefit of those who may be concerned with the implementation of the policy decision to include specific hardening levels in some future GSR's. I will also outline how hardening criteria may be arrived at.

### Background

2. There is nothing new in the idea of requiring weapons, vehicles, and equipment to resist the various effects of nuclear weapons. For a number of years GSR's have included such general phrases as "must be resistant to the effects of Nuclear Weapons", and reference was usually made to WOPS 100, Annex 6 of which, entitled "Protection of Men and Materials in Nuclear Warfare", was an early but creditable effort at quantifying the subject.

3. However, WOPS 100 was not sufficiently explicit in describing the nuclear environment to be resisted. Furthermore, there were no suitable facilities to test new equipment against any stipulated environment, neither was there any R&D Establishment whose terms of reference included research into and advice upon the hardening of Army Equipment. For this reason, as well as others, no more than lip service was ever paid to the subject.

4. During the last few years, however, various factors have re-awakened the Army's attention to nuclear hardening. For example:

a. More became known about the Electromagnetic Pulse (EMP) and its potential effect out to hundreds of miles from GZ in certain circumstances from nuclear bursts outside the atmosphere.

b. The older equipment, whose response to some nuclear effects was reasonably well known (having been tested by exposure to actual weapon tests in the nineteen fifties), was going out of service and was being replaced by equipment that had never been similarly tested. For example the change from Centurion to Chieftain tank, and from C42 Radio to BRUIN.

c. Advances in technology were apparently making new equipment <u>more</u> susceptible to nuclear weapon effects, particularly to radiation (gamma and neutrons) and to EMP. This refers particularly to the introduction of transistorised equipment, and, in future, to microcircuits.

d. AWRE were being drawn into the field of weapon effects and target response, and were actively developing means of simulating the main outputs of the weapon, heat, blast, nuclear radiation (gamma and neutrons), and EMP.

e. More information was reaching UK from the US. The US were embarking on an enormous research programme to evaluate the response of service equipment using mathematical models and simulation techniques to replace weapon tests in the atmosphere which, of course, were banned. It was clear that the amount of information to be obtained from the US would depend very much on the activity shown by UK in the same field.

5. Largely because of these factors the MOD and, in particular, the Army Department instituted a series of studies in AWRE which had the following objectives:

a. To determine more positively the levels of heat, blast, radiation, and EMP that the Army's equipment should withstand.

b. To investigate techniques of design and production that would make equipment "harder" in a nuclear environment.

c. To determine in general terms the vulnerability of new equipment by close study of a very few particular equipments that had just entered service, or were about to enter service (the equipment to be studied were: FACE, C45/BID150 net radio, BRUIN, CLANSMAN, ZB298 Radar. A number of newer equipments have since been added to this list (eg Mine and Shell Fuzes and Mallard).

6. As a result of these separate but inter-related studies, the Army Department is in a much better position to quantify the nuclear environment. Indeed, the Army is doing so in close collaboration with US, and the other two ABCA Countries by assisting in the drafting of a Quadripartite Standardization Agreement (QSTAG) on the subject.

## WDC (NS) and WESG Involvement

7. At their meeting on 18 November 69, the Nuclear Sub committee of the Weapon Development Committee accepted the recommendations of the Weapons Effects Study Group 1969 Report. "The Survival of Service Equipment in a Nuclear Environment".

8. One of the main recommendations made was as follows:

> "Staff Requirements for new equipment should include a clear statement of:
>
> (i) Whether or not to consider nuclear hardening, and if so
> (ii) the nuclear environment to be withstood."

The MGO gave instructions last year that these recommendations were to be implemented.

## International Aspects

9. The USA has already adopted the QSTAG which I have mentioned, and is implementing it. All requirements for new equipments must have nuclear hardening criteria written into them. US R&D Establishments are building up bodies of expertise in the various subjects of heat, blast, radiation, and EMP. Pamphlets and handbooks have been written and commercial firms are being obliged to follow them in order to tender successfully for government contracts. UK contractors must have hardening knowledge if they are to tender successfully.

10. The other ABCA Armies have all adopted the QSTAG, though with some reservations which are expected to be resolved shortly.

11. NATO Countries have also recently accepted in principle "Applied Engineering Publications No. 4" which is the same document as an earlier draft of the QSTAG. It was agreed at a NATO meeting earlier this month that during 1971 AEP4 would be revised so as to be identical to the latest draft QSTAG, and would be ratified at the earliest possible date.

## The Philosophy behind the Selection of Hardening Criteria

12. It was realised quite early that as most Army equipments are operated by men, the survival of such equipment ought to be connected in some way with the survival of its associated men. Much of the early discussion centred on just how to specify this association. Eventually it was proposed, and now accepted, that equipment should continue to function (with nearly 100% certainty) in an environment where the associated man would have a reasonable chance (set at 50%) of continuing to do his job, whatever that might be, for a limited time (set at 1 hour) after the nuclear explosion.

13. It must be stressed that the choice of the criteria, and in particular the choice of 50% survival for 1 hour, were not arbitrary choices, but the result of much discussion and study. However, these parameters are not entirely mandatory - if any sponsor branch feels that there is a case for considering figures other than 50% survival for a hour,

then an appropriate environment can be separately calculated for their special case. For example you may feel that a main battle tank ought to be much harder than this.

14. The choice of 50% survival of men for 1 hour produces certain key associated hardening criteria, such as 3000 rads of radiation, which are found again and again in this subject.

15. When equipment is not associated with a human operator a different philosophy has to be adopted, each case being considered on its own merits, with judgments being made at each stage based on the known characteristics of that particular piece of equipment.

16. Indeed in every case the sponsor must ask himself a number of questions, the answers to which will dictate the way he will eventually determine the hardening criteria to be written into the general staff requirement. The general logical order of these questions form the next part of this talk.

## Hardening Methodology

17. Figure 1 shows the sequence of logical steps involved in establishing hardness criteria, producing, and evaluating equipment against these criteria, and finally identifying the equipment as being in one of the

following categories:

a. Nuclear Unhardened - Nuc U

b. Nuclear Hardened - Nuc H

and in between these two main categories, the compromise case:

c. Nuclear Partially Hardened - Nuc H (P)

There are two distinct phases in the methodology:

Phase 1 - The Sponsor establishes the criteria..

Phase 2 - The R&D establishment, or civilian firm, produces the equipment and it is evaluated against the criteria.

Phase 1 - The Establishment of the Hardening Criteria

18. In Phase 1 the first step is for the General Staff Sponsor to name the equipment and describe its purpose, noting any obvious limiting features such as that it must be man-portable, or that it is carried on or inside a tank, or tracked vehicle, or wheeled vehicle. This step demands a great deal of very careful thought; if the sponsor does not clearly and correctly identify his requirement the design criteria which are subsequently chosen may be inappropriate or wrongly interpreted.

19. Then comes an important first judgment - should nuclear hardening be considered? There may be several reasons why the answer could be 'no' - the equipment may be intended for a non-nuclear theatre (eg "Fox") or the

equipment may be mass produced at low cost and easily replaceable in the field. Whatever the reason, if the answer is 'no' the item is identified as Nuclear Unhardened (Nuc U), and no further action is required except that it might be worth making an estimate of its inherent hardness.

20. If hardening is to be considered, the first job is to specify what we call the threat spectrum, i.e. the range of yields of nuclear weapon to which the equipment might be exposed. This will depend upon whereabouts in the theatre of operations the equipment may be deployed (eg: in the Combat zone, or the comm Z including a port area, etc) and the latest intelligence estimate of the yields of the weapons that the enemy could use against targets in that area. Usually this will be expressed as a range of possible yields between minimum and maximum values. The present estimate of yeilds likely to be experienced in the Corps area is 0.1 KT to 200 KT.

21. Next a check is made to see whether there are hardening criteria already in existence for similar equipment that can be used again. As the subject develops, standard criteria may be developed which may be appropriate. Some preliminary standard criteria have already been developed, and were tabulated in the WESG report last year.

22. Then comes the important consideration of whether a human operator

is involved. First a simple question as to whether a human is essential to the operation of the equipment, and then a more difficult judgment as to whether to base hardness criteria for the equipment on the vulnerability of the man. If the answer to either question is 'no', then no guide lines can be given - the requirement and design concepts must be studied and an estimate, preferably based on sound judgment, made of the hardness criteria to be aimed at.

23. If, however, man <u>is</u> to influence the nuclear hardness, then the sponsor, or the R&D Establishment, must state the likely relationship between the man and the equipment. There are four main categories which should cover most pieces of equipment. They are:

a. Man and equipment both exposed.

b. Man and equipment both protected.

c. Man protected, equipment exposed.

(This includes the possible case of man being protected <u>by</u> the equipment).

d. Man exposed, equipment protected.

If either or both are 'protected' then an estimate must be made of the protection factor or factors against all the main effects.

24. There is now sufficient data to calculate the hardening criteria for that piece of equipment. The basic method is fully explained in the QSTAG being drafted. In outline the steps are as follows:

a. A graph is drawn showing the relationship between yield and distance from ground zero. When man determines hardness, the graph will represent 50% casualties to men with the postulated degree of protection. An example of such a graph is shown in the Vufoil.

b. The curve is cut off between the extremes of the yield spectrum that have been assumed.

c. The values of all the various parameters which describe the nuclear environment (heat, blast, radiation and EMP) are calculated all along the curve between parts A and B, the two extremes of yield.

d. The most stringent parameters seen are extracted and these form the worst case criteria which the equipment should, desirably, survive.

25. The process can be performed by a trained analyst using the procedures given in the QSTAG and data from the standard weapon effects manuals. We have written a computer programme that can do many of the calculations involved. Sponsor branches in difficulties should consult GS(OR)4 who will provide or obtain suitable criteria for particular equipments, though it

must be stressed that sponsor branches and the appropriate R&D establishments should, in future, normally be able to do this themselves.

## Typical Hardening Criteria

26. The result of following the foregoing steps is to produce a set of criteria which the equipment must survive. These criteria will be in the form shown in the Vufoil:

a. Air Blast. Note that air blast parameters include peak static overpressure and peak dynamic pressures, the duration of the pulse, and the total impulses. Note also that we generally have to specify two sets of figures:

Set A - corresponds to a maximum peak overpressure and

Set B - corresponds to a lower overpressure but acting for a longer time, so producing a higher impulse.

It is the dynamic pressure impulse (wind) that is the main cause of damage.

b. Thermal. We specify:

Total thermal energy delivered and figures describing the rate of delivery.

c. Initial Nuclear Radiation. There are two types:

Neutrons and gammas.

Protective factors must be recorded

We specify - total radiation dose - in rads (tissue)

contributions from gamma and neutrons

peak gamma dose-rate

neutron fluence - in neutrons per sq cm

Two radiation effects have to be considered:

Permanent damage, particularly in semiconductor devices - mainly due to neutrons.

Transient electrical disturbances - mainly due to gamma.

d. EMP. We now believe that EMP waveforms can be classified as:

either - from exo-atmospheric bursts

or - from ground or low air bursts.

The main differences are that the pulse from the ground/low air burst lasts longer but is much more local, whereas the exo-atmospheric burst causes a single very sharp spike which may be felt out to hundreds of miles (line of sight).

## Hardening Methodology

## Phase 2 - Evaluating the Equipment against the Criteria

27. The sponsor having established the nuclear hardening criteria, it is now the task of the R&D Establishment and/or the commercial firm to design and produce equipment which will satisfy those criteria. The lower half of Figure 1 shows the steps that will probably be taken to provide a cost effective solution to the requirement.

28. If the equipment does not yet exist, the designer will include the nuclear hardening criteria among the many others to be borne in mind during the Feasibility Study, the Project Study, and the actual Design Phase. The designer should be able to make an estimate of the contribution to the total cost caused by satisfying the hardening criteria - indeed he will make a cost effectiveness study of hardening among his many other cost effectiveness studies. It may well result, even at this early stage, in a relaxation of the criteria or even a decision not to attempt nuclear hardening at all.

29. The equipment is then designed and produced. Clearly the next step is to evaluate its hardness before comparing the hardness with the criteria. This evaluation may be done in a number of ways. For example:

a. By an expert examination of the design, particularly of the electrical circuitry.

b. By exposing models to tests.

c. By exposing the full scale equipments, or parts of it, to tests. Formerly this would have been done at full scale weapon tests, but now the environment has to be simulated.

30. If the hardness evaluation shows that the equipment meets the criteria specified by the sponsor in Phase 1, then the equipment is identified as "Nuclear Hardened", and that is the end of the logical sequence.

31. If, however, the equipment does not meet its hardness specification, then a chain of study, thought, and judgments is initiated. First,

consideration may be given to the possibility of relaxing the criteria. If they can be relaxed, and if the relaxed criteria can be met, then the equipment is again identified as "Nuclear Hardened" and the category and criteria quoted.

32. If the criteria cannot be relaxed then a study of further possible hardening measures is undertaken and an estimate made of their cost. This leads to a judgment as to whether it is worth doing any more. If not, the equipment is identified as "Nuclear Partially Hardened", the hardness level stated, and the limiting factor noted.

33. If it is judged to be worth doing further hardening then this is done followed by another evaluation of its new hardness, and so into the logical chain as before.

34 Three general points should now be made with regard to the Hardening Methodology in Figure 1.

a. Not <u>all</u> equipment will be hardened. The decision is open to the sponsor at the outset to say that hardening should not be considered, and to label it "Nuc U". Even having agreed initially that it should be "Nuc H", the choice is open, later, to partially harden the equipment only.

b. Whatever the stage of design, development, or production of a piece of equipment it fits into the logical diagram of Figure 1 somewhere - a new piece of equipment near or at the top - a near-production item near the lower end. (The FACE equipment, which has been produced and is entering service, has just been evaluated against the stated requirement and has been found to be deficient in some parts. The criteria could not be relaxed, so a study was made of possible methods of hardening, the costs estimated, and a decision taken to do further hardening to one prototype).

c. The methodology flow chart constantly calls for "cost effectiveness" studies at various points in the development period. "Is it worth hardening more". We have, at present, no experience at how this should be done. Perhaps here is an aspect which ought to be investigated by Operations Research workers in the Chief Scientist's Department.

Evaluation of Hardening incl Testing Facilities

35. An adequate range of testing facilities already exist at AWRE, Aldermaston and Foulness. They will be described in later presentations. It is unlikely that the complete range of facilities would be duplicated elsewhere although EMP simulators could be quite easily constructed at other establishments. Requests to test equipment in these facilities should be passed to Ministry of Defence, D Sc 6 via the Sponsor Branch and GS(OR)4.

Summary of Conclusions

36. The "hardening" of equipment against nuclear weapon effects is not a new subject to the Army.

37. This talk has only attempted to introduce you to the outline developments on the subject. Remember that there is to be issued the much more comprehensive QSTAG and NATO agreement. The United Kingdom as one of the Quadripartite countries, and as a member of NATO, must be in a position to understand and implement the Agreements when they are signed and ratified.

38. The layout of the Method of Approach, in Figure 1, is such that sponsor branches, advised if necessary by appropriate R&D establishments, should be able by following the steps in the diagram, plus reference to the QSTAG, to arrive at reasonable hardness criteria that new equipment should be designed to withstand.

39. R&D Establishments, and designers, should after studying the appropriate handbooks, be able fairly quickly to build up a body of expertise in this field in order to meet the hardness criteria that will be stated in future GSR's.

40. Lastly, it cannot be stressed strongly enough that if nuclear hardening is considered early in design, its contribution to the overall cost can be negligible. If it is left until much later, hardening may be difficult and costly - indeed it may be virtually impossible to implement. By studying present day equipments (such as BRUIN) we should hope to avoid pitfalls in future equipments (such as PTARMIGAN).

# HARDENING METHODOLOGY

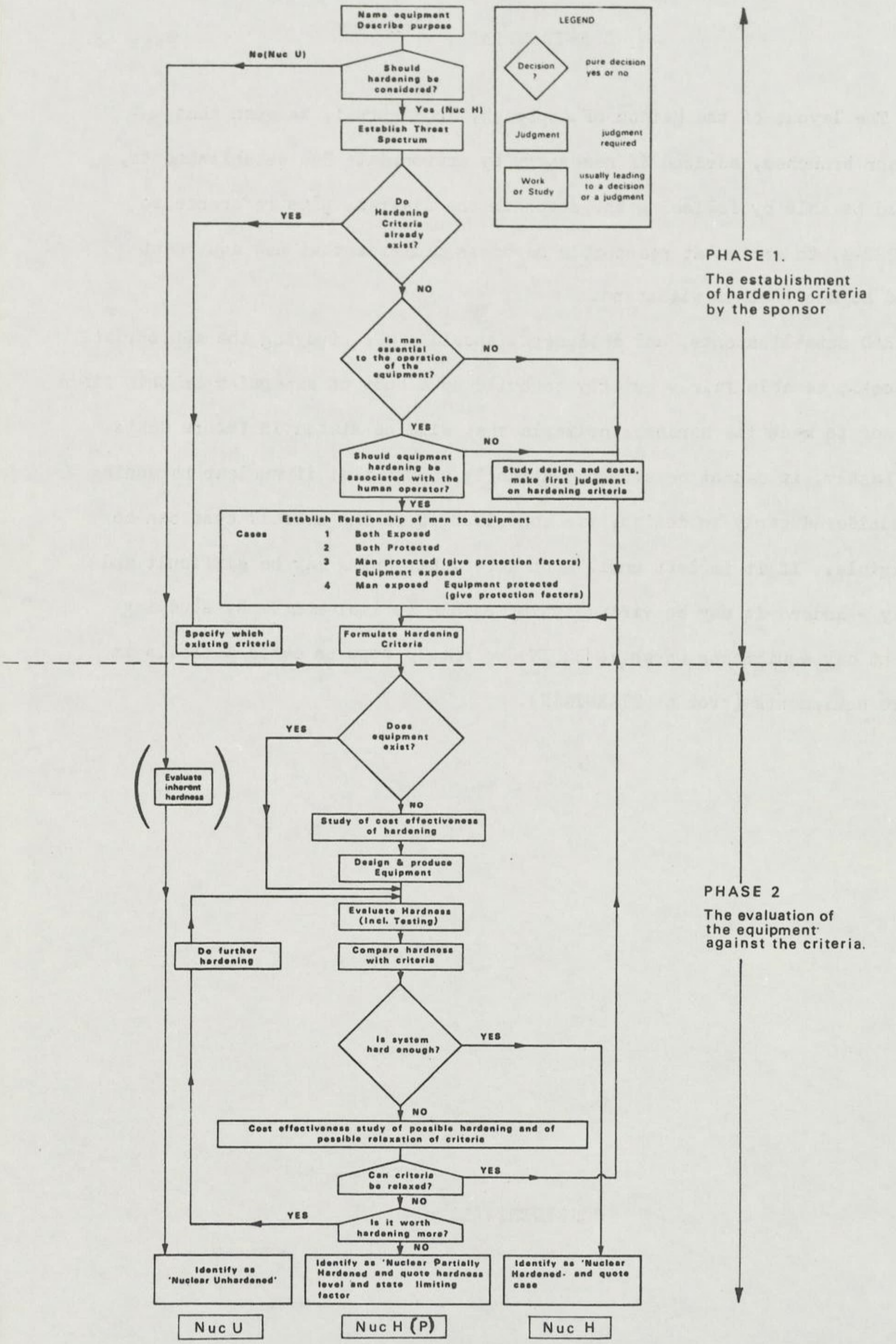


FIGURE 1.

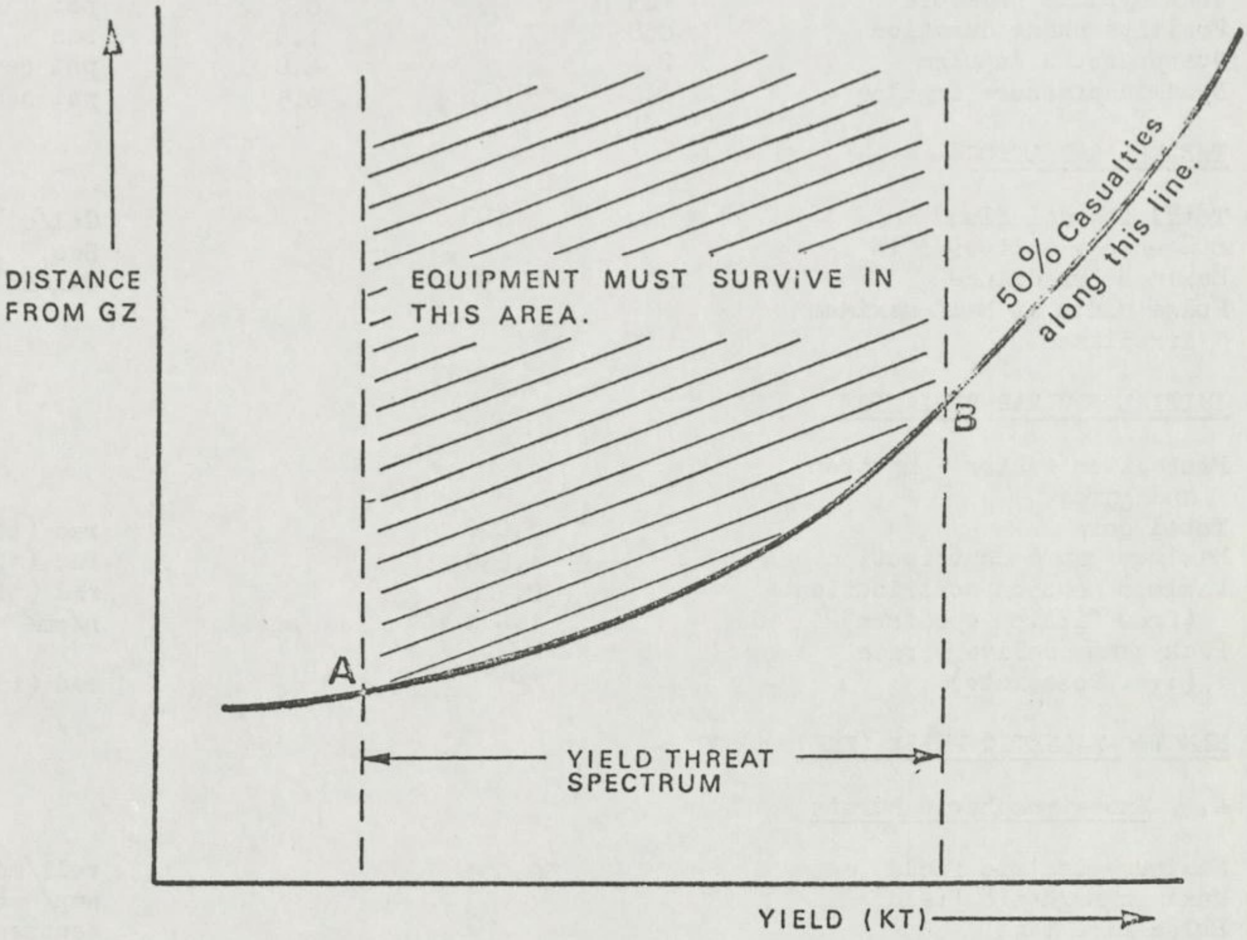


FIGURE 2. THE FORM OF THE GRAPH OF THE DISTANCES FROM GZ AT WHICH MEN ASSOCIATED WITH THE EQUIPMENT HAVE A 50% CHANCE OF SURVIVING FOR 1 HOUR AFTER THE NUCLEAR EXPLOSION. THE HARDENING CRITERIA ARE THE MOST STRINGENT VALUES OF THE NUCLEAR EFFECTS PARAMETERS CALCULATED ALONG THE CURVE BETWEEN POINTS A AND B.

## PROPOSED HARDENING CRITERIA FOR: ELECTRONIC BLACK BOX IN LIGHTLY ARMOURED VEHICLE

### AIR BLAST

| | A | B | Unit |
|---|---|---|---|
| Peak static overpressure | 7 | 5 | psi |
| Peak dynamic pressure | 1.3 | 0.7 | psi |
| Positive phase duration | 0.8 | 1.8 | sec |
| Overpressure impulse | 2.1 | 4.0 | psi sec |
| Dynamic pressure impulse | 0.4 | 0.5 | psi sec |

### THERMAL RADIATION

| | | |
|---|---|---|
| Total thermal flux | 100 | $Cal/cm^2$ |
| 80% energy delivered in | 1.4 | Sec |
| Maximum irradiance | 90 | $Cal/cm^2$ sec |
| Pulse width at half maximum irradiance | 0.6 | |

### INITIAL NUCLEAR RADIATION

| | | |
|---|---|---|
| Protection factor - neutron and gamma | 1 | |
| Total dose | 3,000 | rad (tissue) |
| Maximum gamma contribution | 1,650 | rad (tissue) |
| Maximum neutron contribution | 2,500 | rad (tissue) |
| (from fission spectrum) | $1.4 \times 10^2$ | $n/cm^2$ |
| Peak gamma delivery rate (i.e. Dose rate) | $10^{10}$ | rad (tissue)/se |

### ELECTRO MAGNETIC PULSE (EMP)

A. Exo-atmospheric Bursts

| | | |
|---|---|---|
| Maximum electric field | 50,000 | volt/meter |
| Maximum magnetic field | 150 | amp/meter |
| Pulse rise time | 10 | nanosec |
| Width at half maximum amplitude | 30 | nanosec |
| Overall pulse duration | 100 | nanosec |

B. Ground and Low Air Bursts

| | | |
|---|---|---|
| Maximum electric field | 30,000 | volt/meter |
| Maximum magnetic field | 100 | amp/meter |
| Pulse rise time | 10 | nanosec |
| Duration of plateau after maximum | 200 | microsec |
| Width at half maximum amplitude | 30 | nanosec |
| Electric field at plateau | 10,000 | volt/meter |
| Magnetic field at plateau | 30 | amp/meter |
| Overall pulse duration | 500 | microsec |

## MILITARY ASPECTS

### Air Force Department - The Vulnerability of Strike Aircraft in a Nuclear War Environment

Wg Cdr J Potter (MOD(AIR))

Introduction

1 I would like to take the opportunity to say a few words on the RAF philosophy in assessing the vulnerability of strike aircraft to Nuclear Weapon effects.

2 Aircraft in flight close to a nuclear detonation would be subjected to blast, thermal and nuclear radiation and Electromagnetic Pulse effects, and the pilots could be blinded by the nuclear flash.

3 In a general nuclear war in Europe it is probable that our strike bases and control centre will be destroyed by enemy weapons at an early stage of hostilities, although we expect to recieve sufficient warning to launch our strike aircraft from their bases before this attack. If we assume that our aircraft have escaped the enemy missile strike on their bases we are primarily concerned with the environment through which our strike aircraft will have to fly to reach their targets. We believe that the greatest intensity of Nuclear Activity during the time our aircraft are making their penetration would be encountered in crossing the ground battle zone along the Communist land frontier, as strike aircraft are expected to be routed to avoid pre-planned allied strikes and likely enemy targets (Diagram 1).

4 The actual intensity will vary, dependent on where and when the penetration is made. The highest nuclear intensity is expected in the central zone. Consideration of the narrow slice of the battle zone in this area, through which a strike aircraft will penetrate, extending 20nm either side of the battle front and 10nm either side of the aircraft track, will allow the worst case to be assessed. The time in the zone would vary from 5-6 minutes, depending on the speed of the aircraft and up to 30 nuclear tactical ground or low airbursts might be expected within this zone during the time of crossing. This estimate is based on an AIR CENT assessment of the number of weapon strikes a pilot might see crossing the zone and further work in the United Kingdom. Thirty strikes would represent the maximum feasible rate of fire which would be unlikely to be sustained for long periods. It is considered that a more probable assessment of the sustained intensity of fire would be half the maximum feasible rate (15 strikes in 6 minutes).

5 The intensity of effects within this scenario are considerably affected by assessments of the yield of weapons used. A selection of yields between 1 and 100kt was made for use in a mathematical model designed to investigate the effect of the intensity of thiss environment on aircraft losses. Some larger weapons may be used but these are expected to fall outside the immediate battle area.

6 The effects associated with blast are the most significant as it is considered that a strike aircraft flying at low level will be severely damaged and incapable of flight if it is subjected to blast in excess of 4psi.

7 Probable losses due to blast were established by comparing the areas covered with an overpressure in excess of 4psi with the total area (800 square miles) of the penetration zone, using the Operational Research loss probability formula of Morse and Kimball:

$$P = 1 - e^{-\emptyset}$$

where P = probability of loss

$$\emptyset = \frac{\text{sum of areas of lethality}}{\text{total area}}$$

8 The model is illustrated in Figure 1 showing the 30 bursts within the 800 square miles. From these calculations probable losses were obtained in the order of:

a 14% for the worst case

b 7% for the average case

Thermal Radiation

9 The other nuclear effects were considered in turn and related to the blast effects. In Figure 2 we show the radius of the 4psi blast effects against weapon yield. The thermal radiation effects in red can then be compared in Figure 3. The effects to the left of the 4psi line can be ignored but the aircraft should be hardened to survive those to the right of the line. In certain meteorological circumstances these effects can be considerably enhanced (2 or 3 times) and protection of aircraft rubber seals to 50 cal/cm$^2$ is required to match the 4psi range criteria.

Nuclear Radiation

10 The most significant radiation effect is that of the peak gamma dose rate which is shown in Figure 4. $3 \times 10^8$ rad/sec; equivalent to 150 rad overall radiation, coincides with the 4psi blast criteria, ~~so~~ we have asked for protection to this level. From the MRCA studies such protection does not appear to be cost effective, so we have plotted the $10^7$ rad/sec and the $10^6$ rad/sec lines. Using this data with the loss probability formula we can see the effect of the reduced hardening standards on losses, or more properly in this instance, failure to bomb. The result of adopting a $10^7$ rad/sec peak gamma rate could mean that approximately 9% of the force could fail to bomb, including some 17% of the aircraft experiencing the worst environment. Similarly if radiation protection was abandoned (existing electronic designs are likely to withstand $10^6$ rad/sec) about 13% of the force could fail to bomb through nuclear effects, including 25% of those aircraft experiencing the worst environment (Diagram 2).

Electromagnetic Pulse

11 The electromagnetic pulse effect is considered one of the most serious threats of the nuclear environment. The voltage and power surges expected could put navigation, attack and control systems out of action. EMP from ground or low airburst weapons is not likely to have a serious effect on aircraft which survive blast as the field strength is estimated to be 3-10 kV/m along the 4psi line. EMP from a High Altitude burst is expected to be severe and produce an electric field of 50 kV/m over a very wide area with a radius of several hundreds of miles.

Flash Blindness

12 The risks to the vision of the aircrews through a nuclear environment of up to 30 bursts is very evident. At night without flash blinds the pilot will have a high chance of being temporarily blinded for periods varying from 30 seconds to 2 or 3 minutes, suffering retinal eye damage, and losing night vision for periods up to 25 minutes. This could result in the loss of the aircraft or failure to complete the mission.

Summary

13 It is considered essential to protect strike aircraft against those nuclear effects which have sufficient range to affect aircraft which survive nuclear blast effects equivalent to an overpressure of 4psi.

These effects are:

a Nuclear Flash Blindness

b Thermal Radiation

c Radiation Effects, including the peak gamma dose rate

d EMP from a high level burst of 50 kV/m

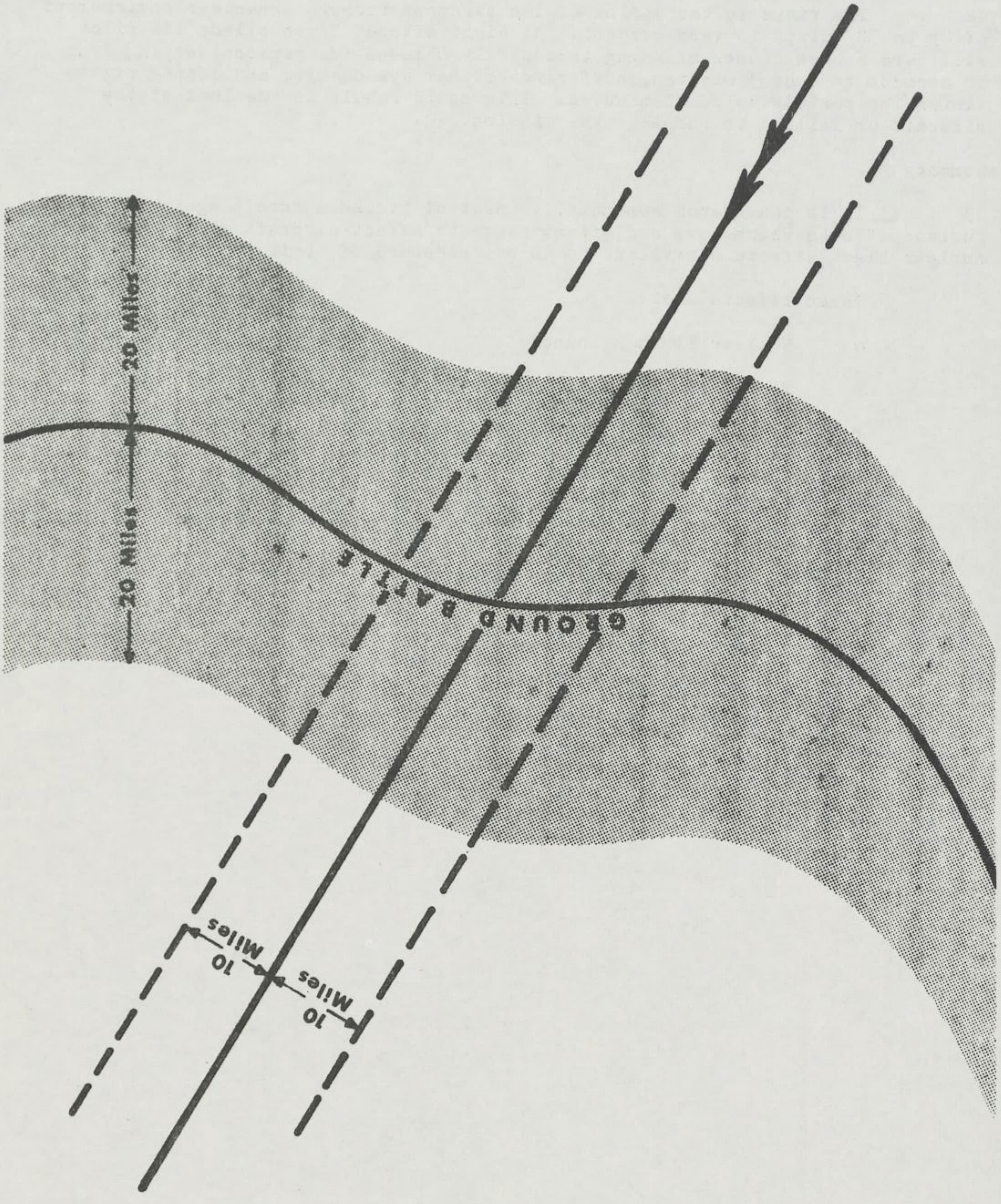
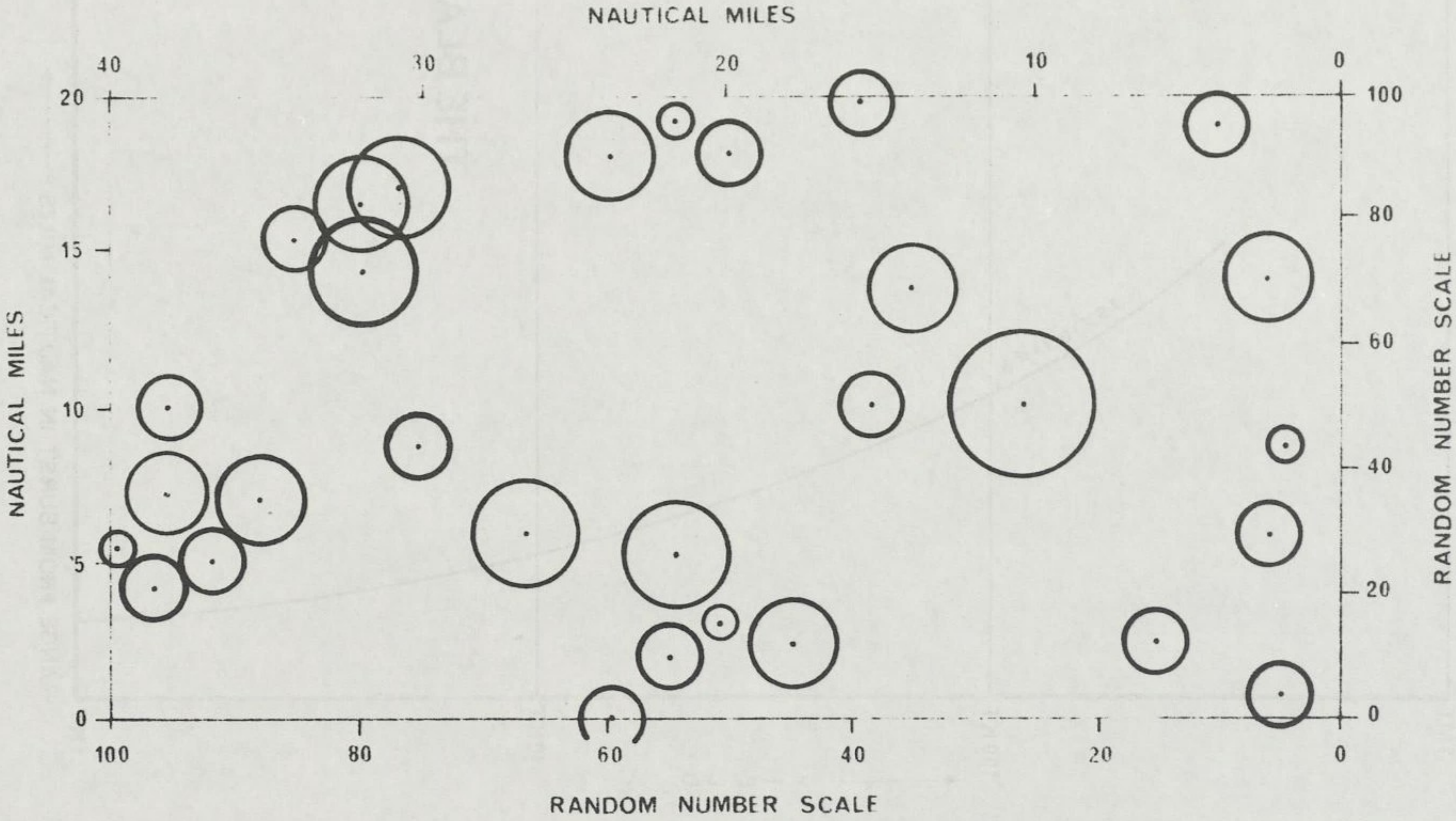


DIAGRAM 1

FIGURE 1

Fig. 1 MODEL OF NUCLEAR ENVIRONMENT



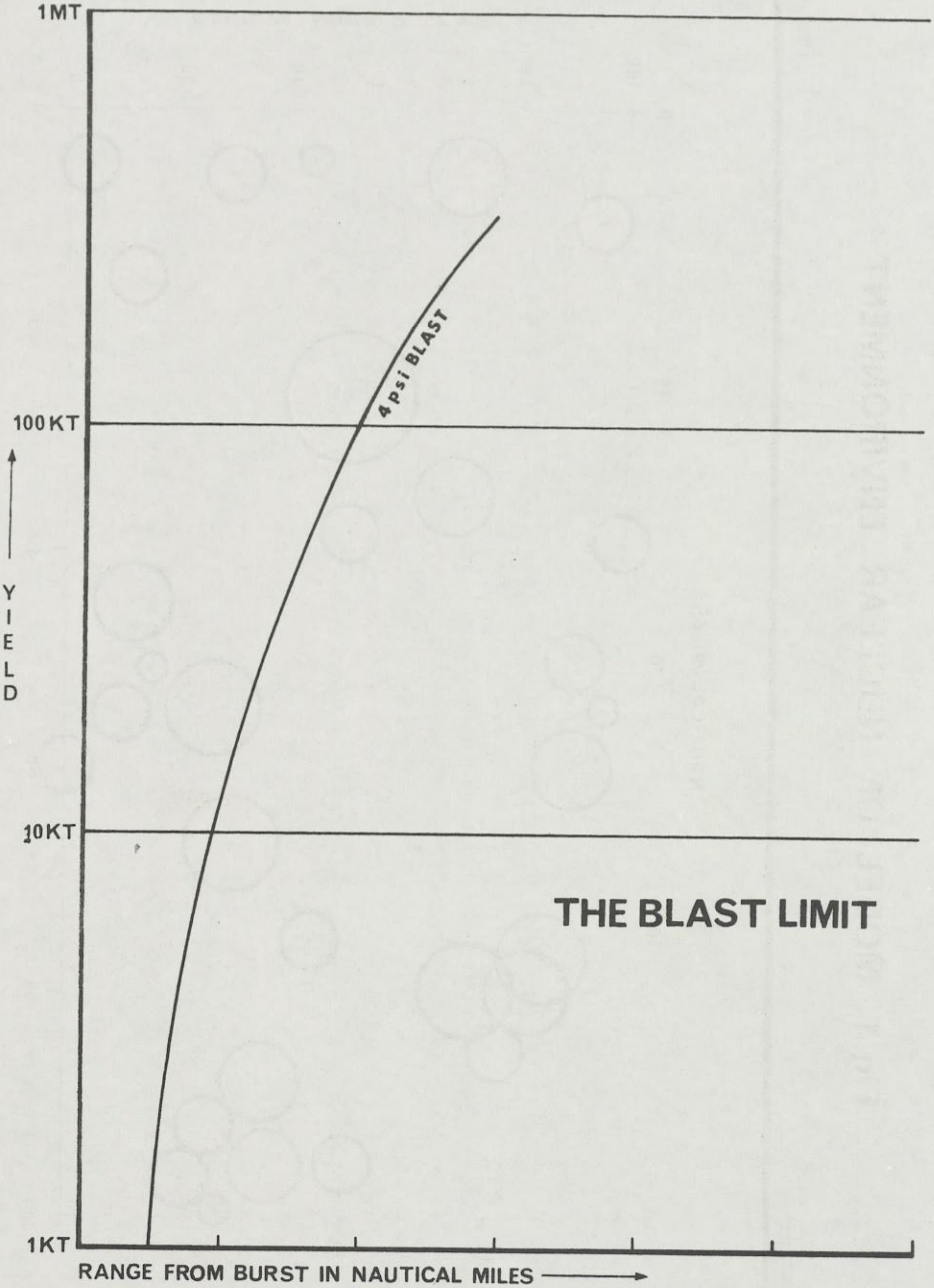

1MT
100KT
10KT
1KT
YIELD
4psi BLAST
THE BLAST LIMIT
RANGE FROM BURST IN NAUTICAL MILES

FIGURE 2

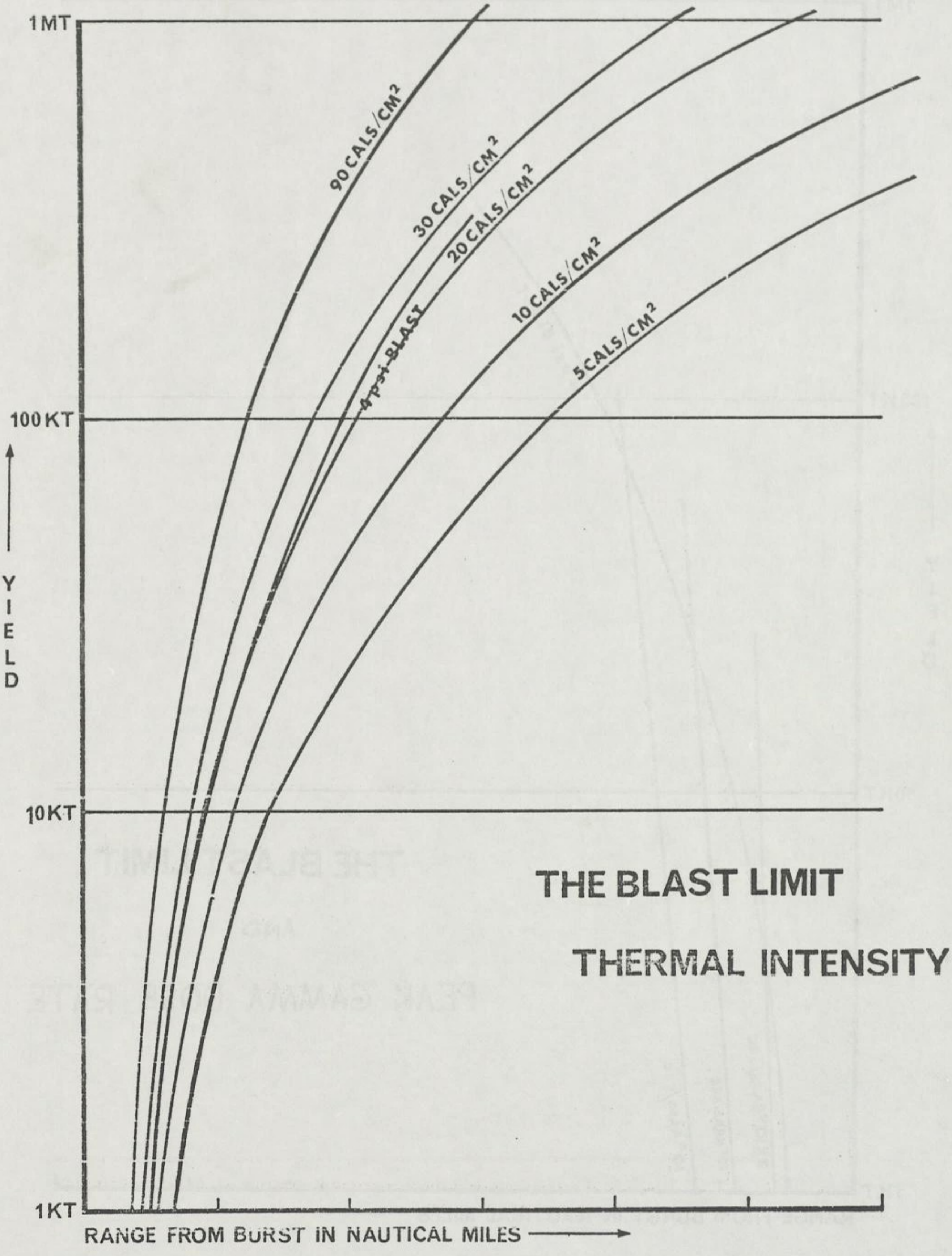
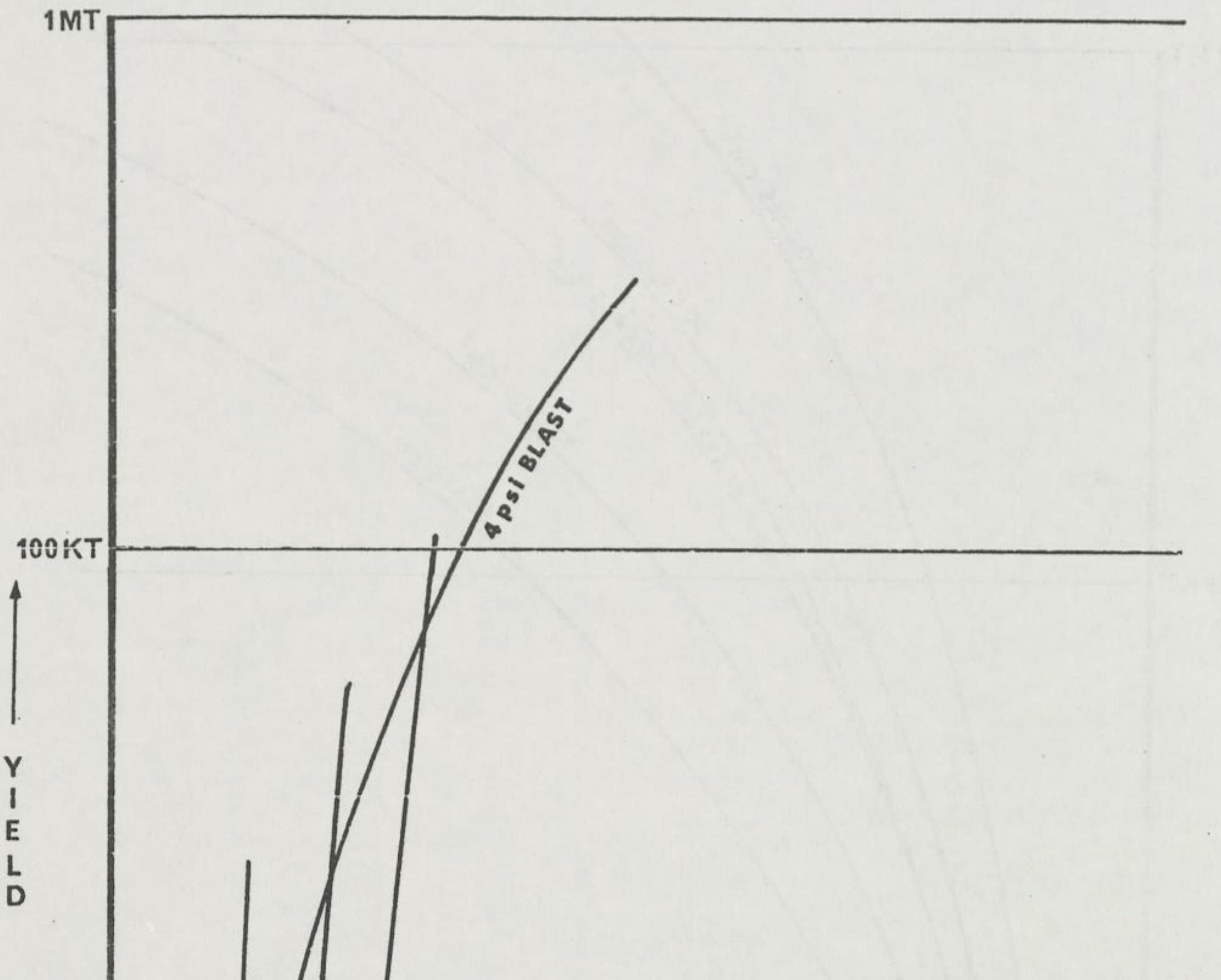

1MT
100KT
10KT
1KT
YIELD
RANGE FROM BURST IN NAUTICAL MILES
90 CALS/CM²
30 CALS/CM²
20 CALS/CM²
4 psi BLAST
10 CALS/CM²
5 CALS/CM²
THE BLAST LIMIT
THERMAL INTENSITY

FIGURE 3



THE BLAST LIMIT

AND

PEAK GAMMA DOSE RATE

FIGURE 4

| GAMMA HARDENING LEVEL | MAXIMUM LOSS | AVERAGE LOSS |
|---|---|---|
| ~ 150 RAD ($3 \times 10^8$ RAD/SEC) | 14% | 7% |
| ~ 10 RAD ($10^7$ RAD/SEC) | 17% | 9% |
| 1 TO 2 RAD ($10^6$ RAD/SEC) | 25% | 13% |

DIAGRAM 2

## INTERNATIONAL ACTIVITIES

### The Technical Co-operation Programme (TTCP)

D James (D Sc 6 (MOD))

1 The purpose of this session is to describe the international co-operation which takes place in the field of Nuclear Weapon Effects. I shall confine my remarks to the co-operation between America, Canada, Australia, and Britain under the aegis of the Technical Co-operation Programme. Later on you will hear about co-operation in NATO; between Britain, Norway and the Netherlands (ANN); and between Germany, Italy and Britain on nuclear weapon effects in relation to the MRCA project.

2 Many of you will be aware, and indeed participate in, TTCP activities but for the benefit of those who are not familiar with the TTCP organisation I will describe briefly the overall set-up before dealing in some detail with the Nuclear Weapons Effects Sub-Group identified as Sub-Group N.

3 The organisation was first formed in 1957 as the Tripartite Technical Co-operative Programme to facilitate co-operation between the United States, Canada and the United Kingdom in non-atomic research and development, and make easier the communication between working scientists and technologists in the three countries. It was envisaged that the exchanges that take place would contribute to a better use of the scientific and technical development effort in each of the three participating countries.

4 In 1965 Australia joined the organisation and the title was changed to The Technical Co-operation Programme so that the letters TTCP could remain. At the end of last year New Zealand joined the organisation but initially will be limiting their activities to Sub-Group G.

5 The organisation shown in Figure 1 is controlled by a sub-committee for non-atomic military research and development (NAMRAD), the UK member being CA(PR). The NAMRAD committee itself meets annually and the day to day business is conducted and controlled by the Washington Deputies, the UK representative on this being the Head of DRDS in Washington DC. At present this is a Mr W H Stephens. At functional level the organisation is divided into 17 Sub-Groups; these may operate as entities or form Working Panels to deal with particular aspects. The Working Panels in turn may set up Working Groups for particular tasks.

6 It is worth pointing out at this stage that in TTCP activities the major participant and provider of information has been the United States. Recently the position of executive members of various Sub-Groups has been devolved to other countries. This move is in line with United States policy of getting the other 3 countries to contribute more to TTCP activities.

7 Turning now to the Nuclear Weapons Effects Sub-Group (Sub-Group N), it is to some extent unique in that it is part of an organisation that deals with co-operation in the non-atomic field. Sub-Group N and TTCP itself has evolved through the years to meet the changing requirements of the participants. It should be borne in mind that by and large Sub-Group N has operated largely as a medium for information exchanges, with a large quantity of information

emanating initially from the United States. Indeed, without this information it is unlikely that the UK could have reached the position it is in today in its understanding of nuclear weapon effects.

8 The present organisation is shown in Figure 2 and it can be seen that Sub-Group N now consists of 4 Working Panels:- N-2; N-5; N-6 and N-7; Working Panels N-1; N-3 and N-4 having disappeared since the Sub-Group was first formed.

Panel N-2 deals with Blast and Thermal Shock and has as its UK leader Mr N S Thumpston of AWRE, Foulness. It has 5 Working Groups considering such fields as new energy sources and simulation techniques and in the future will be looking at the blast effects on different materials after those materials have been subjected to thermal effects.

Panel N-5 deals with the effects on personnel and has as its UK national leader Surgeon Commander Hughes of Naval Nuclear Technical and Safety Panel (MOD). It has 2 Working Groups, one dealing with chemoprophylaxis, and a newly formed Working Group covering military radiation measurement and human response. The search for a chemoprophylactic agent to enable man to survive even for a small period of time over and above that which he can survive at the moment is an important but difficult task. A comprehensive report on therapy regimes has been issued under the auspices of N-5 recently and this report will serve a useful function for reference purposes. Before leaving N-5 it is worth pointing out that this Panel is concerned with all aspects of nuclear weapon effects on personnel eg blast and radiation. N-5 and N-2 already collaborate on thermal effects.

Panel N-6 deals with radio propagation and radiation transport and has as its UK national leader Dr P Flynn of AWRE, Aldermaston. This is a newly formed Panel which met for the first time in the United States a few days ago. Its terms of reference are to co-ordinate effort for ensuring full interchange of information, personnel and material on radio wave propagation, effects of the medium on communications and radar, nuclear radiation transport, nuclear cross sections and code development.

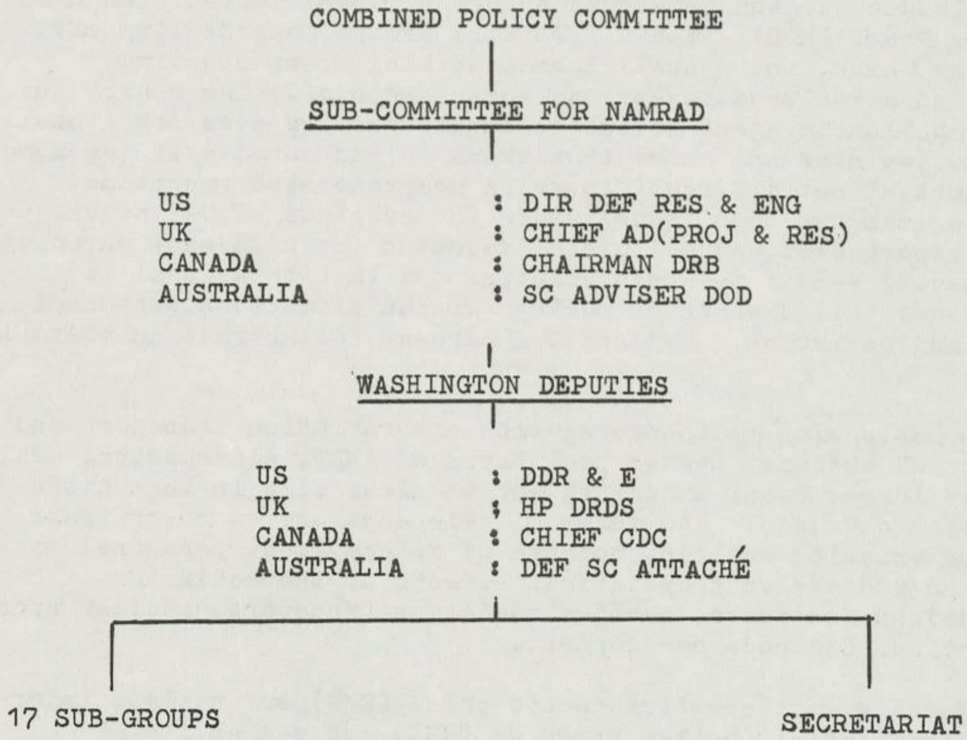
Panel N-7 deals with electromagnetic pulse (EMP) and nuclear interaction with material (better known as TREE) and has as its UK national leader Mr J D Davies of AWRE, Aldermaston. This Panel met for the first time in September and, together with N-6, during the past year superceded the old Panel N-4. You will be hearing more of the practical effects of the co-operative studies being carried out by the UK members of this Panel during the next two lectures.

9 The UK national leader and executive member of Sub-Group N is Dr F H Panton, ACSA(N) and it follows that it is his responsibility, in conjunction with other national leaders, to ensure that Panels and their Working Groups fulfil the original purpose of TTCP and to report back to the Washington Deputies that the co-operative programme is proceeding as originally envisaged; in other words that collaboration between working scientists and technologists and communication between these groups is taking place. It is also his function as executive Member to ensure that all 4 countries are aware of the

problems in each country and the work being done to overcome them. To some extent the success or failure of these efforts is dependent upon the amount of time and effort each country is prepared to devote to the problems involved and covered by Sub-Group N.

FIGURE 1

ORGANISATION OF TTCP



COMBINED POLICY COMMITTEE

SUB-COMMITTEE FOR NAMRAD

US : DIR DEF RES & ENG
UK : CHIEF AD(PROJ & RES)
CANADA : CHAIRMAN DRB
AUSTRALIA : SC ADVISER DOD

WASHINGTON DEPUTIES

US : DDR & E
UK : HP DRDS
CANADA : CHIEF CDC
AUSTRALIA : DEF SC ATTACHÉ

17 SUB-GROUPS

SECRETARIAT

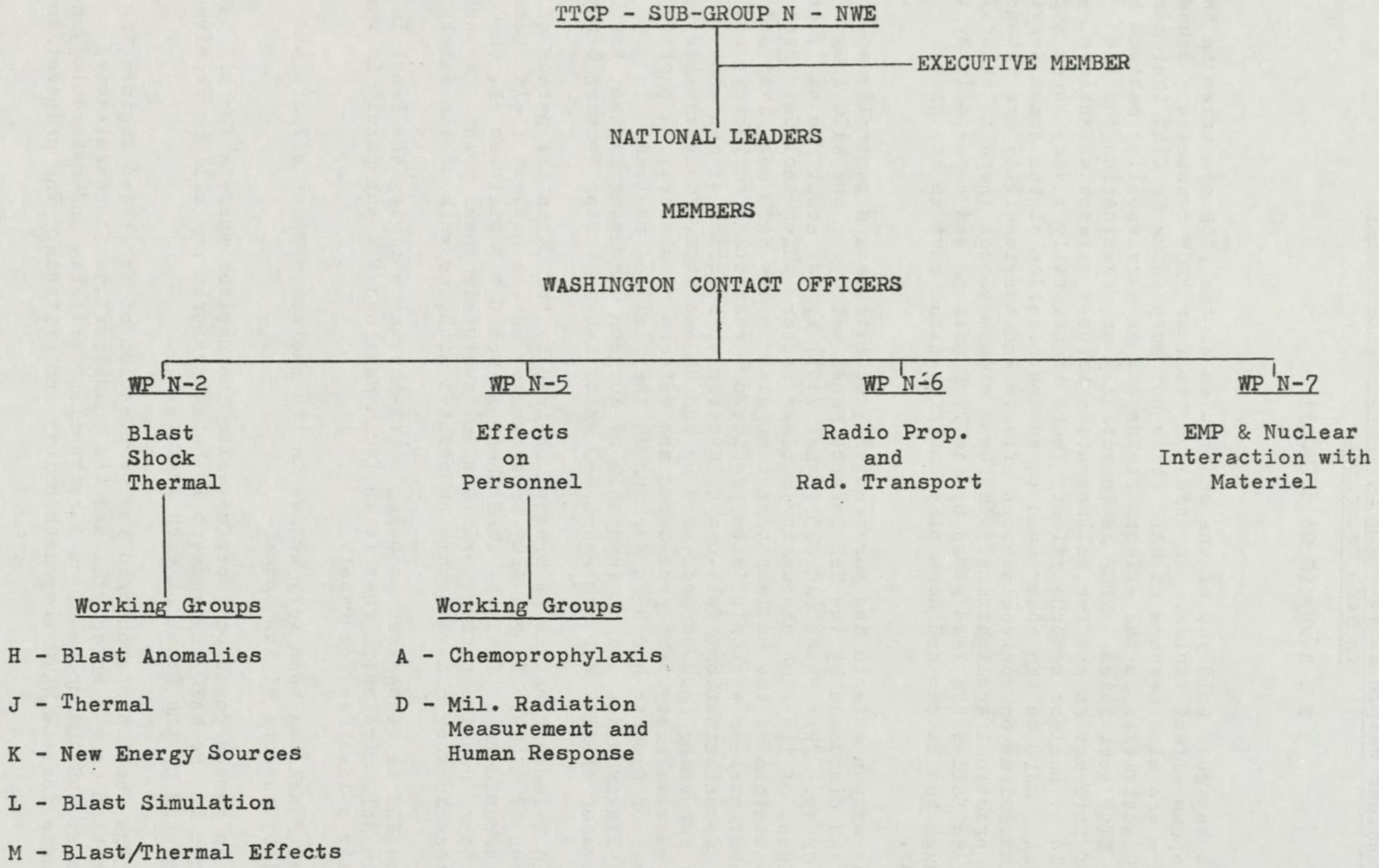

TTCP - SUB-GROUP N - NWE
EXECUTIVE MEMBER
NATIONAL LEADERS
MEMBERS
WASHINGTON CONTACT OFFICERS
WP N-2
Blast
Shock
Thermal
WP N-5
Effects
on
Personnel
WP N-6
Radio Prop.
and
Rad. Transport
WP N-7
EMP & Nuclear
Interaction with
Materiel
Working Groups
H - Blast Anomalies
J - Thermal
K - New Energy Sources
L - Blast Simulation
M - Blast/Thermal Effects
Working Groups
A - Chemoprophylaxis
D - Mil. Radiation
Measurement and
Human Response

FIGURE 2

## Nuclear Weapon Effects and Equipment Survivability in NATO Countries

W N Saxby (D Sc 6 (MOD))

1 D James has just told you of the activities of the TTCP countries in the nuclear weapons effect fields. As three of the four TTCP countries - Canada, USA and UK - are also members of NATO it is not surprising to find that many of the NATO activities in the effects fields and on survivability matters are similar to TTCP activities. TTCP is essentially an organisation for the exchange of information and for collaboration between defence scientists, and in the field of nuclear weapons effects there is naturally a very large input from the USA. NATO on the other hand is an organisation of the Armed Services and the discussions on nuclear weapons effects and survivability are intended to lead to practical applications. In these circumstances there is naturally a tendency to follow the lead given by the TTCP nations and especially by the USA, although the UK can and does play an influential part in the NATO discussions.

2 Nuclear weapon effects and survivability activities are generally co-ordinated and discussed by the NBC Defence Panel set up by the NATO Army Armaments Group. This Panel (AC/225 (Panel V11)) spends about one half, or a little less, of its time discussing nuclear matters which include, inter alia: discussions of the nuclear threat spectra in the NATO sea, land and air environments; nuclear weapon effects prediction; radiation; dosimetry; radiac equipment; decontamination; fall-out prediction; protection of men and equipment; hardening (or, as preferred by the US and NATO, "survivability") criteria; survivability test procedures and effects simulators. A particularly useful Group of Experts has been working in the field of nuclear chemoprophyllaxis under the chairmanship of Surgeon Commander Hughes, the UK National Leader of TTCP Working Panel N-5 which has a similar Working Group.

3 The NBC Defence Panel is at present chaired by the UK in the person of Col P Budden of GS(OR)4 in the Army Department. In the nuclear field there is a considerable input from the AWRE where Lt Col D W B Williams RE, the Senior Military Representative, provides an invaluable focal point. Recently we in Defence Science 6 have become associated with the work of the Panel.

4 Because NBC is recognised as being a tri-Service activity the Panel is a rarity in NATO circles in that it includes Naval and Air sub-panels in what is primarily a land Service Panel.

5 The NBC Panel has been very active in the nuclear weapons effects and survivability aspects of its tasks:-

5.1 An agreed position paper covering the nuclear threats for all three Services in the NATO environment is being prepared and will be received and updated by the Panel at each meeting.

5.2 The Panel has sponsored the preparation of an Allied Engineering Publication (AEP4) which will use the Quadripartite Standardisation Agreement (QSTAG) document on survivability criteria and methodology as the basis for the NATO army methodology and criteria. The preparation of

AEP4 is in step with, but about a year behind, the equivalent stage of the QSTAG. Nevertheless, as a draft, it is already being used by the armies of some NATO countries. We have now the position that there is a common survivability methodology and, to all intents and purposes, common survivability criteria in both NATO and TTCP armies.

5.3.1 Recently a Group of Experts, at present under my chairmanship as a member of D Sc 6, has been set up to consider the test procedures and facilities needed to assess the survivability of defence equipment against nuclear weapons effects. As a first measure the Group is to produce a manual of the facilities in operation in each of the NATO countries. Afterwards it will discuss what collaborative programmes can be undertaken and whether or not more facilities are needed for NATO. It will discuss instrumentation, intercalibration problems and the passage of information on facilities and effects.

5.3.2 The Group has asked for Contact Offices to be appointed in each of the ten countries involved; for the UK the Contact Office will be D Sc 6, MOD. It has also requested four Designated Nations, each to act as a focal point for one of the main effects - France for Thermal Effects, the Federal Republic of Germany for Nuclear Radiation Effects, Norway for Electromagnetic Pulses Effects and UK for Blast and Shock Effects.

5.3.3 Finally the Group recognised that in establishing hardening criteria there are a number of practical problems in abstracting the relevant data from the references quoted in the QSTAG and in AEP4. At the Group's request the USA has agreed to abstract the necessary data and to publish the relevant items in a convenient form for use by staff officers.

6 Within NATO the USA has extensive survivability test facilities and programmes covering all its Services. The UK has a considerable programme and a number of facilities although these are by no means comprehensive: these will be described later. Canada has programmes and facilities covering blast, thermal and radiation effects. Germany has test facilities covering blast, thermal and radiation. France has also extensive facilities in these fields, with particularly impressive blast simulators built in disused railway tunnels, and a number of solar furnaces for thermal effects. France is designing an EMP simulator. Norway is concentrating on EMP and blast work. Italy is building up blast and radiation facilities. Belgium has some work on radiation effects. Netherlands is considering the problems of radiation and man, and the EMP environment.

7 Within NATO contact between the individual member nations in encouraged. The UK has had exchanges in blast simulators with Italy, and on EMP with Norway. In the EMP field the UK; Norway and Netherlands also meet together under the Anglo-Netherlands-Norwegian Collaborative Programme (ANN) to collaborate on the effects of EM Pulses and in EMP simulator design. For the ANN project the UK Contact Officer is Mr D J Collyer of AWRE.

8 I have indicated briefly the fields in which we are working with NATO, together with the organisations involved. Nuclear weapons effects and survivability are important features of the NATO activities and the UK is performing a valuable function both in providing information and in influencing the NATO nations. I have talked largely of committee activities and collaborative exchanges; of more immediate practical value is perhaps the MRCA project involving UK, Germany and Italy, and Wing Commander Potter will now tell you more about this.

## INTERNATIONAL ACTIVITIES

### The MRCA Project

Wg Cdr J Potter (MOD(AIR))

1 The NATO Multi Role Combat Aircraft is being produced as a joint project by the United Kingdom, the Federal Republic of Germany and Italy. A joint international management staff (NAMMA) has been set up by the countries concerned in Munich to control the design, development and production of the aircraft by Panavia and Avionica, international companies formed for the purpose.

2 The Ministry of Defence Air Staff Requirement (ASR) for the aircraft called for nuclear hardening to the following levels:

a Blast: 4 psi overpressure

b Thermal Radiation: 50 $cal/cm^2$

c Nuclear Radiation: 150 rad (at $3 \times 10^8$ rad/sec peak gamma dose rate)

d Electromagnetic Pulse: 24 kV/m

The MOD asked to be advised of the costs and timescale penalties involved in meeting these requirements.

3 These criteria were accepted by NAMMA in the Performance Design Requirement (PDR) passed through Panavia to Avionica, who tasked EASAMS (UK) to examine the problem of evaluating the hardening of avionic equipments against the requirement. This evaluation costed EMP protection to 24 kV/m at approximately £6,000 per aircraft and protection against $3 \times 10^8$ rad/sec peak gamma rate as £150,000 per aircraft.

4 The report recommended the adoption of a $10^7$ rad/sec peak gamma dose rate, equivalent to 10 rad overall radiation. The report has been taken by NAMMA and the UK recommendation for the acceptance of the $10^7$ rad/sec level was adopted. In addition, EMP requirements were reviewed at the UK request and revised to provide protection against 50 kV/m peak E-field. Avionica has been tasked to evaluate the cost and timescale of adopting these levels of protection. Detailed hardening specifications for individual equipments are now being prepared and issued by NAMMA.

# FACILITIES FOR EFFECTS WORK

Facilities in use at AWRE in December 1970

A D Greenhalgh (AWRE)

## 1 Introduction

These notes briefly list the facilities in use at AWRE in December 1970, for simulating the initial effects from nuclear weapon explosions. Details of performance are now being quoted in SI units but for convenience the more commonly recognised units are also given in some instances. Photographs of the equipments given during the lecture and on display at the time of the symposium have been omitted.

## 2 Blast

A large blast tunnel is located at AWRE, Foulness, Essex, capable of simulating the blast wave from nuclear weapons. It consists of a stepped cylindrical steel tunnel about 140m long, and of varying widths up to 5m. Sections may be removed so that equipment under test may be placed within them. Within the dimensional limits either full scale equipment (up to the size of a Chieftan tank (50 tonne)) or, where appropriate and relevant, scale models may be tested. One section (Section 2) is designed to allow buried structures to be tested with dimensions up to 3m x 1.8m and buried to a depth of about 2.2m. Complete instrumentation facilities are available. Performance details are shown below, the overpressures quoted are the maximum practicable that can be achieved.

| Test Section | Diameter (m) | Overpressure $kN/m^2$ (psi) | Positive duration (s) | Impulse $kNs/m^2$ (psi.s) |
|---|---|---|---|---|
| 1 | 4.88 | 73 (10.5) | 0.2 | 3.3 (0.48) |
| 2 | 2.44 | 173 (25) | 0.15 | 8.6 (1.25) |
| 3 | 2.44 | 296 (43) | 0.125 | 9.3 (1.35) |
| 4 | 1.83 | 620 (90) | 0.09 | 11.7 (1.7) |

There is also a vertical shock tube at AWRE, Foulness for carrying out tests on buried structural elements.

| | |
|---|---|
| Diameter | 0.6m |
| Reflected Pressure | 1.5MN/m$^2$ (220psi) |
| Pulse Length | 0.012s |

AWRE, Foulness has also considerable experience in and facilities for simulating nuclear weapon blast effects on structures, by conducting tests on scale models of structures (constructed at Foulness) with appropriately scaled quantities of conventional explosives.

## 3 Thermal

A thermal simulator has been constructed at AWRE, Foulness, consisting of a unique design of a high power argon arc mounted in a double parabolic mirror furnace.

| | |
|---|---|
| Target Area | 1cm x 1cm |
| Max Uniform Irradiance | 3.5MW/m$^2$ (83 cal.s$^{-1}$.cm$^{-2}$) over 1cm$^2$ at a power input of 32kw |
| Pulse Shape | Rectangular (the leading edge has a rise time of 10-15ms) |
| Pulse Length | Variable up to several seconds |
| Max Thermal Energy | Up to 10MJ/m$^2$ (240cal/cm$^2$) |

With a corresponding reduction in irradiance uniform fluxes can be produced over flat areas up to 15cm x 15cm.

## 4 TREE

The following facilities are located at AWRE, Aldermaston:

### 4.1 EROS - Flash X-ray Generator

| | |
|---|---|
| Spectrum | X-Radiation similar to that from a nuclear burst |
| Dose | Up to 1000Rad per pulse at 1m (Dose falls to about 50% at 45° angle) |
| Pulse Rate | Between 2 and 10 pulses per day |

| | |
|---|---|
| Pulse Length | About 80ns |
| Stored Energy | 400kJ |

Typically, at 0.5m a box 0.6m x 0.3m x 0.3m in size can be irradiated with a 3000Rad pulse.

### 4.2 VIPER - Pulsed Fast Reactor

| | |
|---|---|
| Pulse Source | Up to about 3 x $10^{17}$ fissions |
| Pulse width at ½ max | About 400 μs |
| Max peak $\gamma$-dose rate | About 6 x $10^{8}$ Rad/s |
| Spectrum | Pulse resembles that of a nuclear fission burst, but it is broadened slightly at the low energy end. |

| Test Position | Container Size | Dose | Neutron Fluence |
|---|---|---|---|
| Central Cavity | 3.5cm x 3.7cm dia | 1.3 x $10^{5}$rad | 1 x $10^{15}$n/cm$^{2}$ |
| Irradiation Cave: | 30cm cube | | |
| Inner Face | | 3.5 x $10^{4}$rad | |
| Centre | | 1.1 x $10^{4}$rad | |
| Outer Face | | 8 x $10^{3}$rad | |
| Reflector Cavities (2) | 7.5cm x 3.7cm dia | 6 x $10^{3}$rad | 5 x $10^{13}$n/cm$^{2}$ |
| Top Outer Surface of Reflector | Suitable for "black boxes" - eg C45 No 1 | 1.1 x $10^{3}$rad | 3 x $10^{13}$n/cm$^{2}$ |

### 4.3 HERALD - Light Water Research Reactor

Various irradiation facilities are available in this reactor which is operated at a steady level of 5MW and in this context is primarily a material and equipment test reactor. The following details are typical:

| | |
|---|---|
| Fast neutron flux | $6.2 \times 10^{11}$ n cm$^{-2}$s$^{-1}$, E > 2.5MeV |
| Thermal flux | $5 \times 10^{13}$ n cm$^{-2}$s$^{-1}$ |
| $\gamma$-flux | About $2 \times 10^{4}$ rad/s |
| Max Equipment size | About 15cm long x 5cm dia |
| Irradiation Times | As required |

4.4 LINACS - 15MeV Vickers Linac

Linear accelerators, used in the electron beam mode, are useful for specific purposes, such as the measurement of photocurrents in semi-conductors. The target area is, however, small and has to be virtually planar as electrons have low penetration.

| | |
|---|---|
| Energy Range | 6 - 15MeV |
| Pulse duration range | 12ns; 50ns; and 0.5 to 4 μs |
| Rise Time | 10ns; ~ 0.1 μs |
| Max current in pulse | 500mA |
| Electron Beam size | 2000cm$^2$ to 1cm$^2$ |
| Dose rate | $10^6$ rad/s to $10^{11}$ rad/s |
| $\gamma$-field at 1m - central value | $10^4$ rad |
| Area of ½ central value | 350cm$^2$ |
| PRF range | 1 - 100pps or single shot |

5 EMP

An outdoor elevated transmission line facility known as PETS 1 (Pulsed Electromagnetic Threat Simulator) is located at AWRE, Aldermaston. The enclosed volume is 15m long, 4m wide and 3m tall, giving an ideal working volume of about 3m x 0,8m x 0.6m and a maximum working volume of about 10m x 2.5m x 2m. It has in fact been used to test equipment mounted in an APC, the top of which is about 2.5m from the ground plane. There are two pulse generators providing approximately simple models of the EMP for exo-atmospheric and low airbursts, ie

(a) a pulse with a rise time which can be as short as 10ns and with a decay period of about 25ns.

(b) a pulse with a rise time which again can be as short as 10ns but with a decay period of about 15µs.

The maximum electric field strengths are about 50kV/m.

AWRE are currently considering the provision of further facilities and I will hand over to Mr Sellek to describe these to you.

# Future EMP Simulators at AWRE

W H Sellek (AWRE)

## 1. INTRODUCTION

Simulation of the EMP at AWRE has been limited to simple models of exo-atmospheric and ground burst pulses in the 3 m high PETS1 facility. Some service equipment has been tested in this facility and some of the equipment was housed in vehicles such as Landrovers and Armoured Personnel Carriers. The metallic structure of these vehicles produces severe field distortions within the facility because they occupy a large proportion of the linear dimensions of the facility. Ideally a simulator should be restricted to equipments with linear dimensions no greater than half those of the working volume.

## 2. FUTURE TRANSMISSION LINE SIMULATORS (PETS 2)

Plans are now ahead at AWRE for building PETS 2 which is a larger simulator. The working volume of the structure will be 6 m high, 11 m wide and 25 m long. This will enable us to accommodate a number of vehicles at the same time - for example, four cable-linked 3 ton army trucks (as shown in Figure 1).

Improved pulse generators will be required to drive the facility, and the development of the "exo-atmospheric" generator is in hand. The simple model ground burst pulse used in PETS 1 can be repeated in PETS 2 but, if the current thoughts on the military worst case conditions are to be met, the endo-atmospheric pulse poses considerable problems. For example we may be required to represent a pulse with a dominant H field peaking at 1,800 A/m, with a risetime of a few tens of nanoseconds, followed by a plateau at about one sixth of the peak amplitude lasting some two hundred microseconds and decaying in a further 300 microseconds. To produce such a field in the PETS 2 simulator we should require an energy store of megojoules. Further, because of the plane wave nature of this facility there would be a considerable over test of the E field. Ideally, a special simulator should be constructed to deal with such endo-atmospheric environments.

## 3. SIMULATORS FOR EXTENDED SYSTEMS

In order to test large area systems such as communications centres with long interconnecting cables, we need to know the response of the system as a whole. The pickup on the cables is seen as one of the most important factors affecting the system susceptibility. As it appears that the main threat to such a system would come from the exo-atmospheric burst we have turned our attention to the design of a vertical monopole radiating system, with a peak source power of 25 megawatts to simulate this pulse.

The monopole has five main features: (Figure 2)

1. A generator to pulse charge the radiating aerial to 1 megavolt.
2. A spark-gap system to launch a step current wave up the aerial.
3. A 3 metre cone section diverging to a diameter of 5 metres to radiate the pulse edge.
4. A resistive cage 30 metres high to attenuate the current wave and produce a radiated pulse with an exponential decay.
5. A suspension system for the monopole some 30 metres high.

We require a uniform field distribution over the test area. This entails operating the radiator at ranges up to 1 kilometre from the site. The field strength at this range will, with the proposed system, reduce to a few hundred volts per metre. This is considerably lower than the postulated threat fields. The results therefore will need extrapolating for the threat level response, either by analysis or simulating the full level response, by injecting currents of the appropriate amplitudes and shapes into the system. These would be determined from records taken at the test site under the radiating pulse environment.

All the simulators mentioned so far are limited to producing vertically polarised fields. The exo-atmospheric threat at maximum intensity occurs with the source near the overhead position. The fields travel downwards and are horizontally polarised. To simulate such an environment it will be necessary to suspend a dipole system over the test area by, for example, balloon or helicopter. The problems associated with such systems can readily be appreciated when it is seen that the dipole needs to be about 100 m long, some 5 m diameter at its centre, contain a complete megavolt pulse generator, and that the whole system needs to be suspended at a height of a few thousand feet over the test area (Figure 3).

An alternative which is much less expensive but limited in application is a ground based long wire system with an aerial cage mounted horizontally and supported from tall poles or masts. The obvious height limitation will result in the radiated signal arriving at glancing incidence. Nevertheless we could obtain valuable information on system performance prior to building simulators in the sky (Figure 4).

With all radiating systems the instrumentation problem is increased. All tests will need to be correlated with field mapping and the results recorded in detail so that some confidence can be placed in extrapolation by an order of magnitude.

## Summary on Future EMP Simulators

To summarise we see the simulator programme, in the near future, as follows:

1. A PETS 2 facility providing the full threat fields of the exo-atmospheric burst and a simple ground burst model. The facility will accommodate up to four large vehicles at one time.
2. A vertical monopole radiating system to simulate the exo-atmospheric burst model at low level over a large area.
3. A long wire radiating system to provide data on the system effects from low level fields with horizontal polarisation.

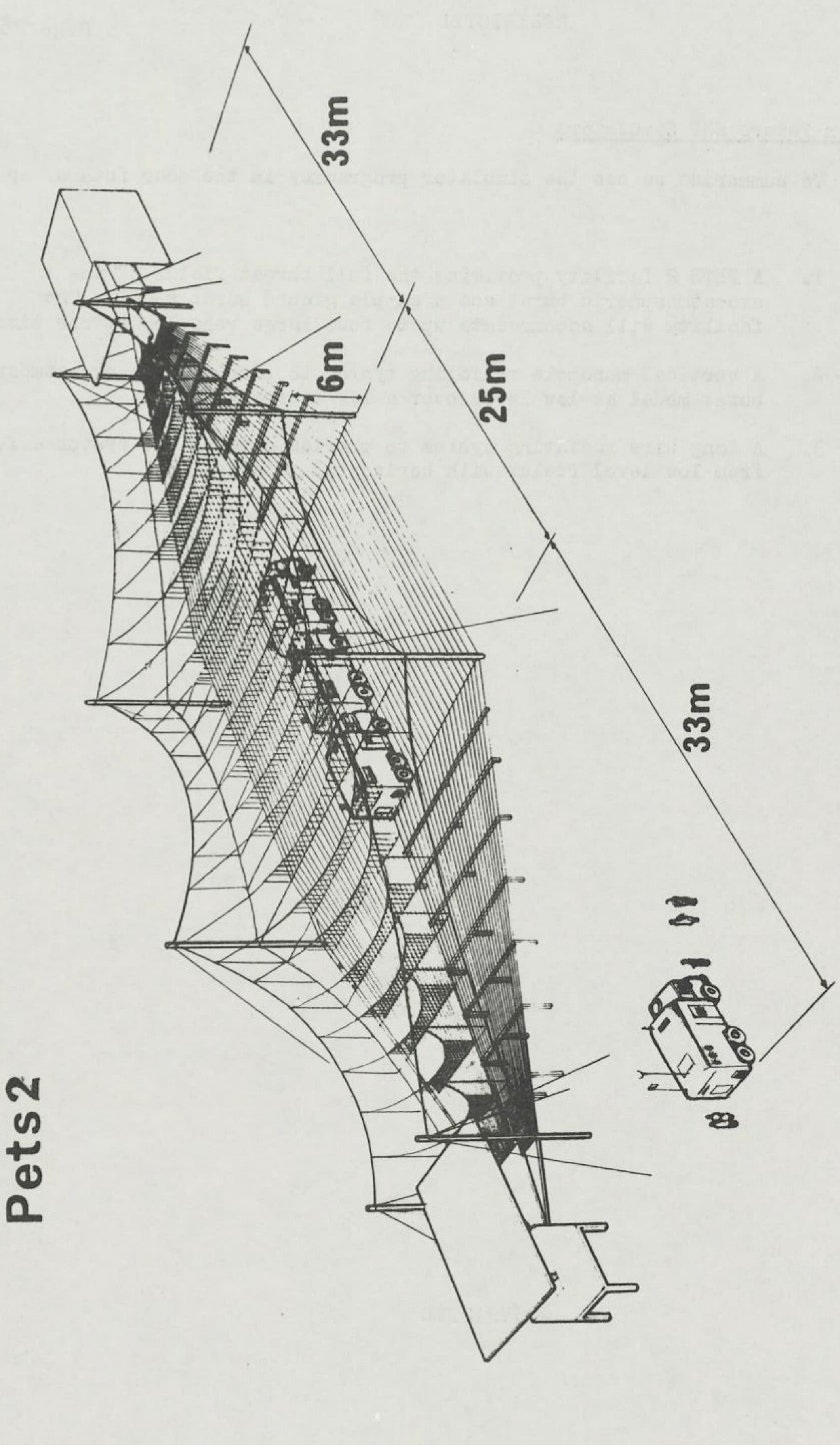


FIGURE 1

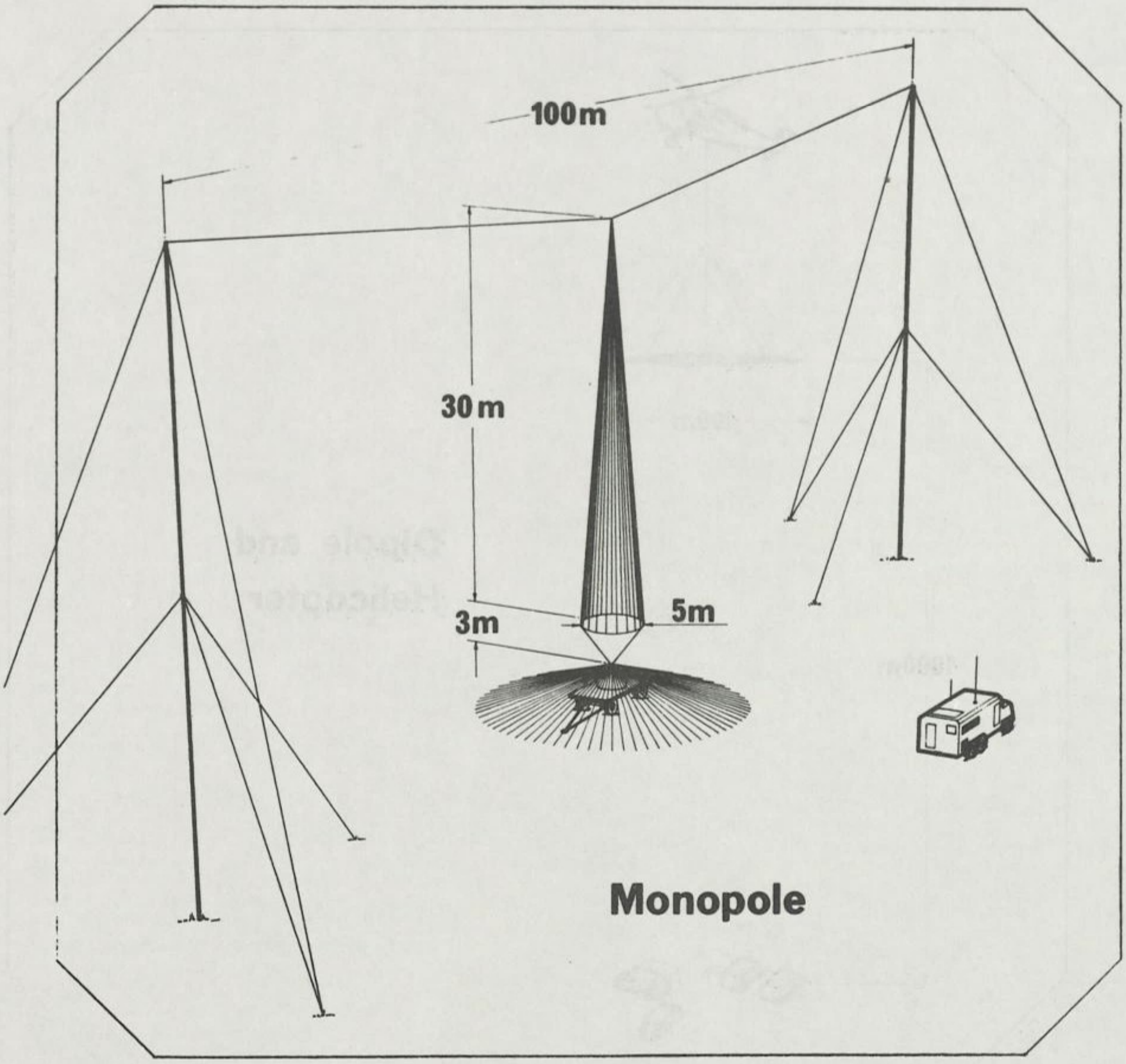


FIGURE 2

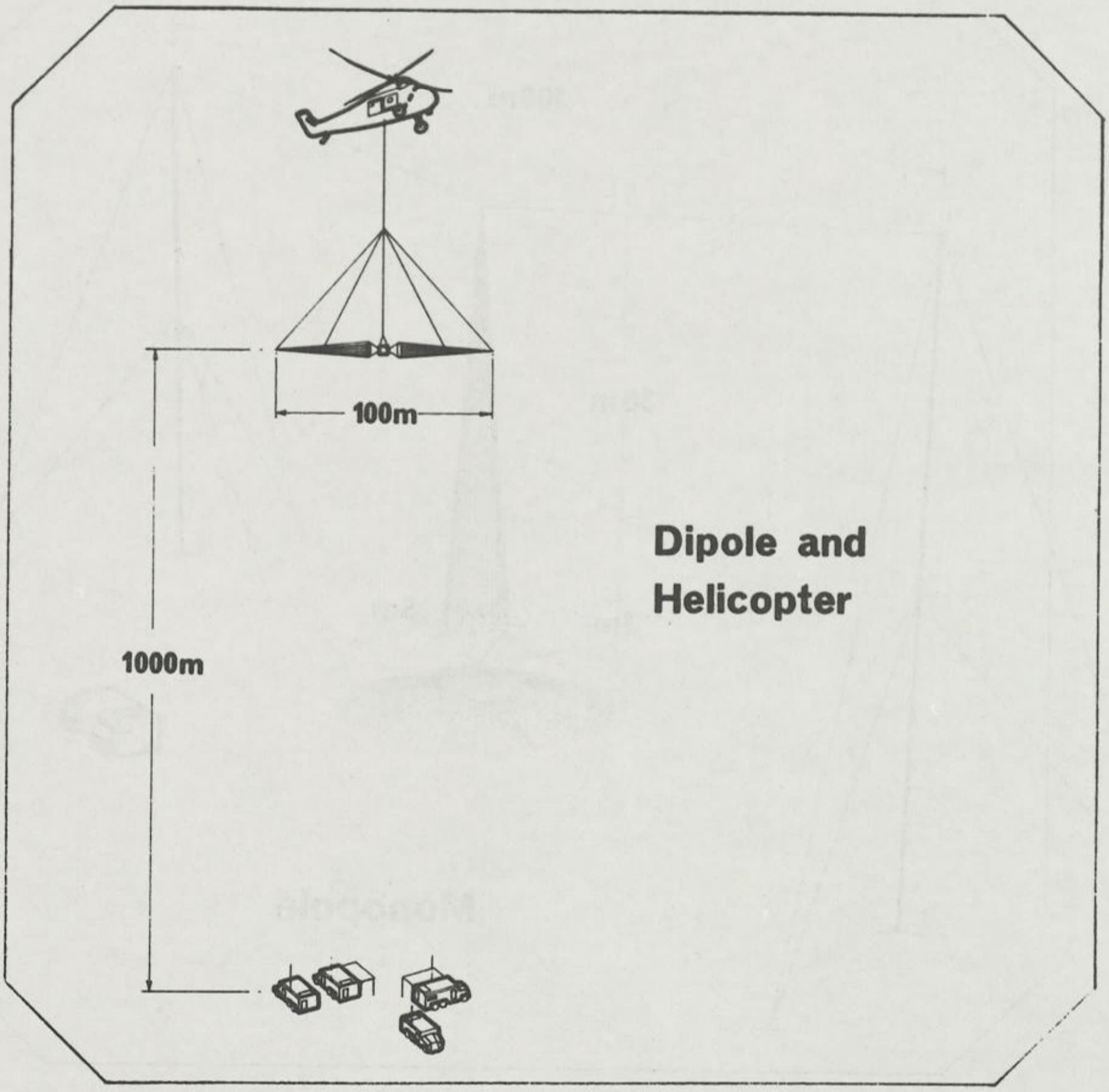


FIGURE 3

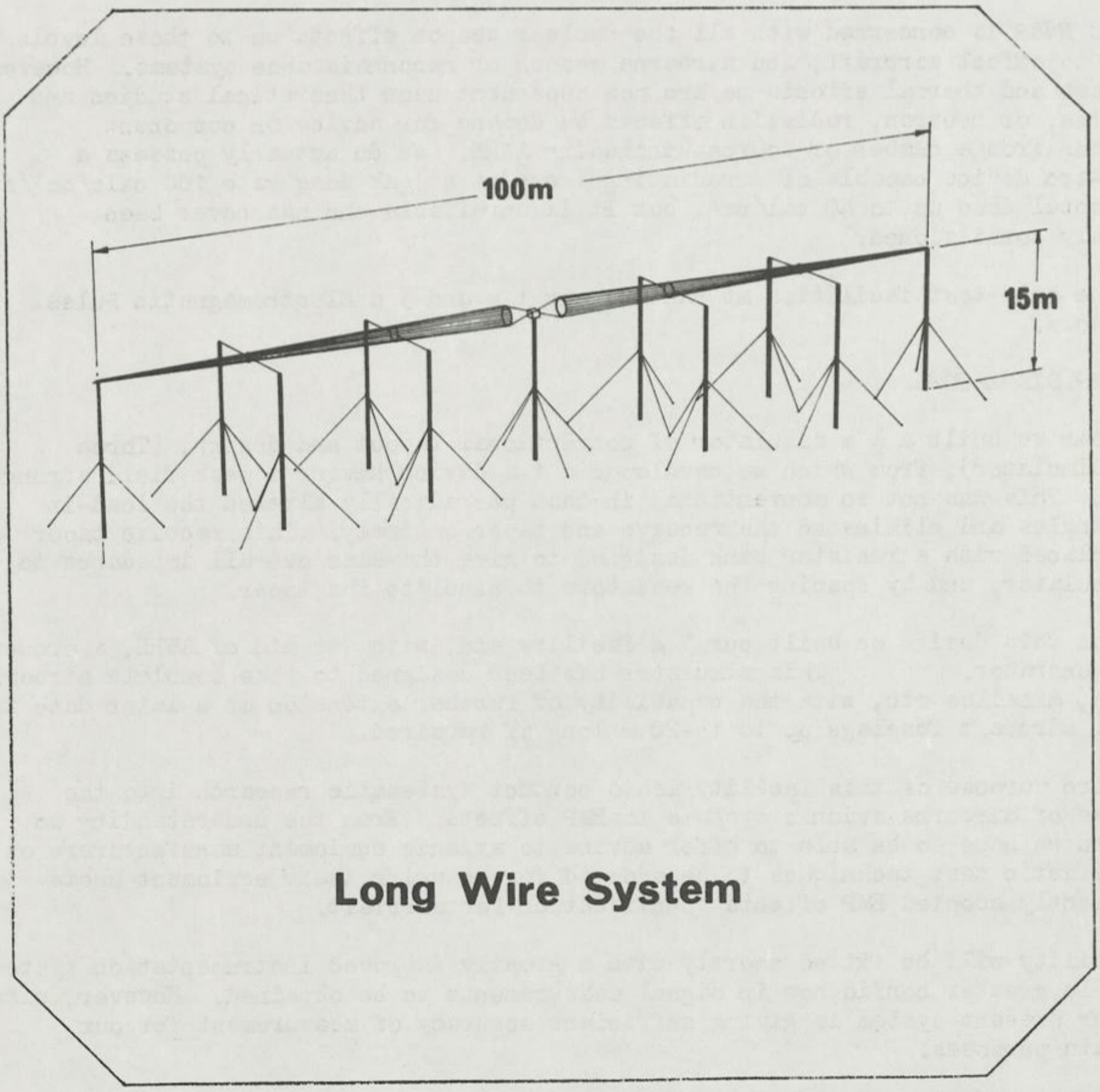


FIGURE 4

# FACILITIES FOR EFFECTS WORK

## RAE Nuclear Weapon Effects Test Facilities for Airborne Avionic Systems

P H Reed (RAE)

## 1 INTRODUCTION

The RAE NWEP is concerned with all the nuclear weapon effects up to those levels likely to affect aircraft, and airborne weapon or reconnaissance systems. However, for blast and thermal effects we are now dependent upon theoretical studies and for gamma, or neutron, radiation effects we depend for advice on component selection from a number of sources including AWRE. We do actually possess a carbon-arc device capable of irradiating 1 $cm^2$ at a peak dose rate 100 $cals/cm^2/sec$ and a total dose up to 40 $cal/cm^2$, but it is unreliable and has never been seriously commissioned.

Thus the only test facilities at RAE are our 1 m and 3 m Electromagnetic Pulse simulators.

## 2 EMP SIMULATORS

This year we built a $\frac{1}{2}$ m simulator of conventional layout and design, (Three Plate Simulator), from which we developed a 1 m device having a peak field strength 1 kV/m. This was not so conventional in that we radically altered the lead-in taper angles and eliminated the receive end taper entirely. This receive taper was replaced with a resistor bank designed to give the same overall impedance to the simulator, and by spacing the resistors to simulate the taper.

Based on this design we built our 3 m facility and, with the aid of AWRE, a proper pulse generator. This simulator has been designed to take complete airborne systems, missiles etc, with the capability of further extension at a later date to take an aircraft fuselage up to 15-20 m long if required.

The prime purpose of this facility is to conduct systematic research into the response of airborne avionic systems to EMP effects. From the understanding so obtained we hope to be able to offer advice to avionic equipment manufacturers on the realistic test techniques to be adopted for ensuring their equipment meets the recently adopted EMP effects specification for aircraft.

The facility will be fitted shortly with a greatly improved instrumentation system to enable greater confidence in signal measurements to be obtained. However, with care our present system is giving sufficient accuracy of measurement for our immediate purposes.

The pulse capability of the 3 m facility is shown in Fig 1 and compared with the AWRE and DSc6 recommended pulse shapes. For our purposes we use the spectral analysis of these pulses, as given in Fig 2.

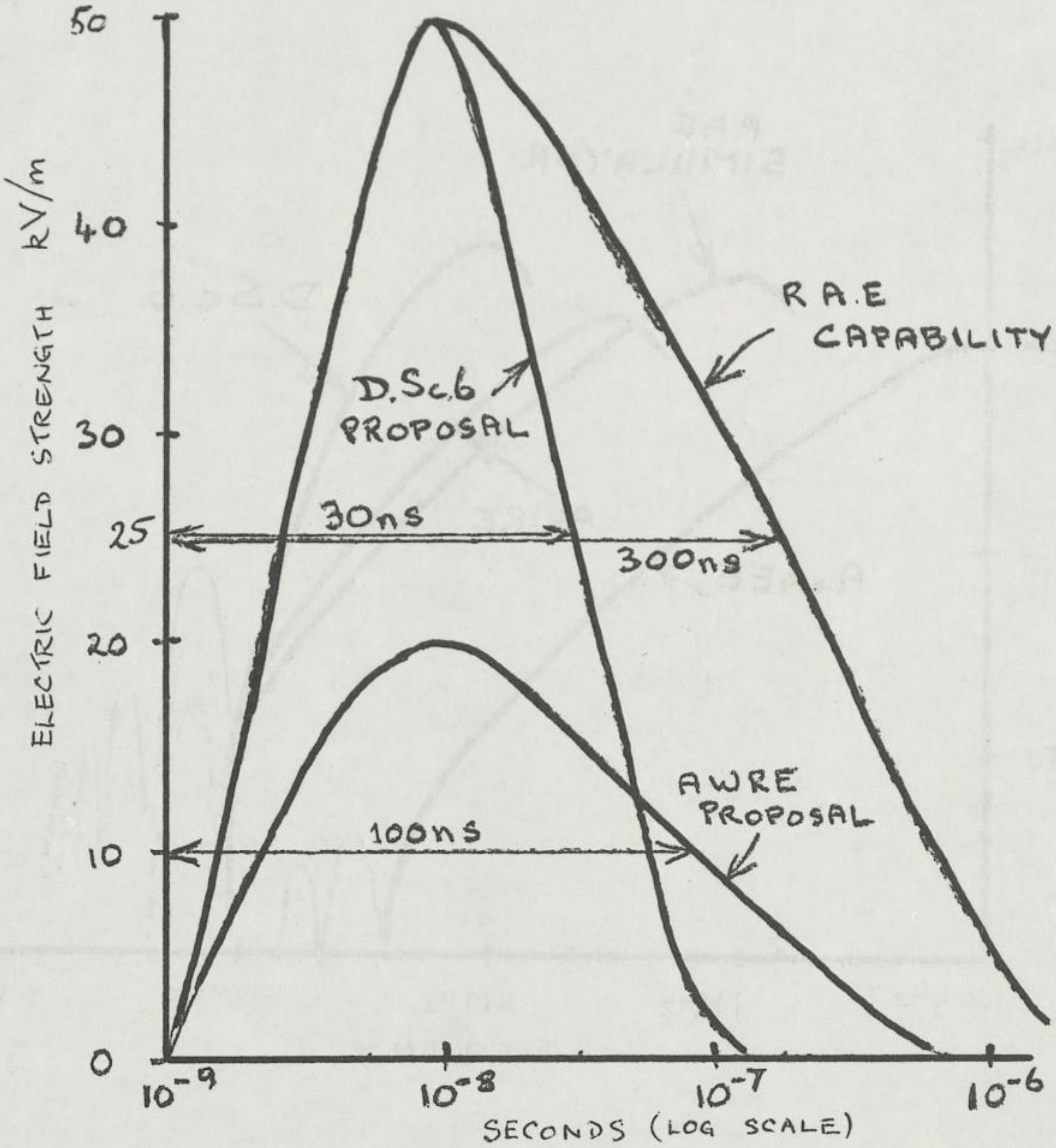


FIGURE 1 PULSE SHAPES

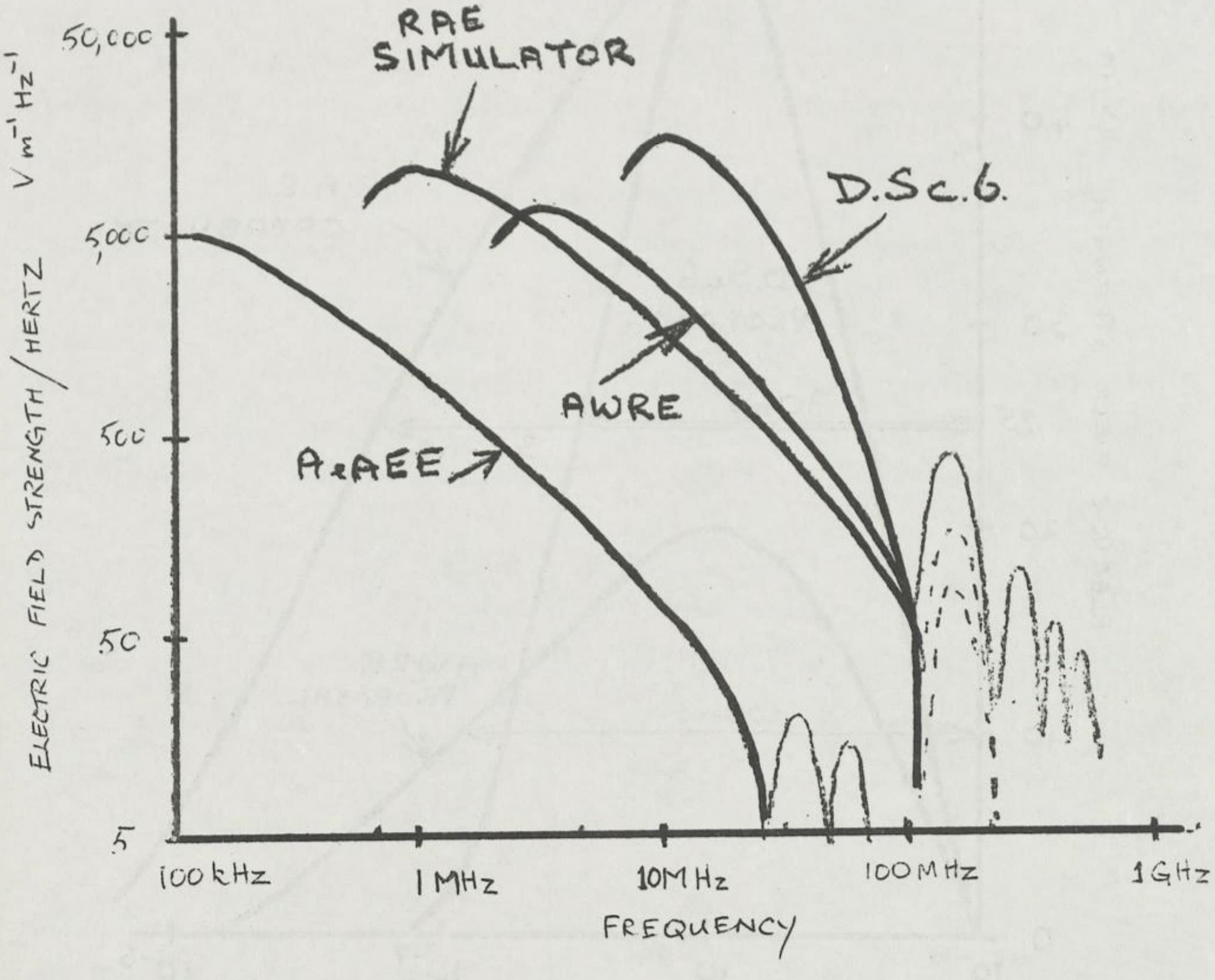

RAE SIMULATOR
D.Sc.6.
AWRE
A.AEE
50,000
5,000
500
50
5
ELECTRIC FIELD STRENGTH / HERTZ V m$^{-1}$ Hz$^{-1}$
100 kHz
1 MHz
10 MHz
100 MHz
1 GHz
FREQUENCY

FIGURE 2.

## FACILITIES FOR EFFECTS WORK

### EMP Test Facilities at A&AEE

G F Hocking (A&AEE)

### Introduction

1 Some of you may be mystified by the initials "A&AEE" therefore I will explain that this refers to the Aeroplane and Armament Experimental Establishment which is located on Salisbury Plain. This is more commonly known as Boscombe Down and is the Ministry of Aviation Supply's establishment responsible for testing or otherwise assessing military aircraft and their armaments.

### The Test Rig

2 The Boscombe Down rig which you see in Figure 1 was constructed and erected by AWRE just over 2 years ago for the specific purpose of attempting a quick assessment of how a nuclear EMP might affect a Vulcan aircraft.

3 As you can see this rig consists of an aerial system and a ground plane. The aerial of aluminium tubes is suspended 30 ft up by terylene ropes supported from wooden poles and the ground plane consists of aluminium strips fixed to the hard standing. The working area of the rig is approximately 120 ft square and accomodates a Vulcan aircraft. To achieve the pulse rise time on restricted site area it was necessary to arrange the feed and terminations in the form of double tapers.

4 The rig is energised by either of 2 Marx type generators. The smaller is capable of producing a pulse of up to 2 kV/m and is free running at about 12 pulses per minute. The large generator will normally produce pulses from 10 kV to 35 kV per meter. In this each pulse is fired individually and a measurement usually requires about 10 min from start to finish.

5 These generators produce, in the aerial, pulses with an e-folding rise time of some 15 and 20 ns respectively, with a decay to the half amplitude point of approximately 3.5 μs. At an amplitude of 25 kV/m this pulse was considered at that time to be reasonably representative of a 'threat' level pulse.

6 The response of the aircraft's circuitry to the EMP is recorded by oscillograms using a 50 MHz band width oscilloscope. Because of the environment this equipment had to be enclosed, with its integral power supply, in a double screened box 4ft x 2ft x 2ft. Consequently at present, we are limited to measurements in aircraft which can contain this equipment.

### Future Work

7 Future work will entail the modification of these facilities for two main reasons:-

The first is that current opinion of the shape and magnitude of the 'threat' pulse differs from that postulated 2 years ago.

Secondly, as information must be obtained to guide the design of smaller aircraft the cumbrous recording equipment must be changed.

8 To cover the first point it is intended to obtain a new generator and to modify the aerial system to produce a faster and narrower pulse. Further, when modifying the aerial, the need for varying the test aircraft's attitude to the wavefront will be considered.

9 To reduce the size of the equipment it is necessary to physically separate the sensor from the recorder. Previous attempts at this using various interconnecting cables have proved to be unsuccessful because of the environment. To eliminate interference with the transmission of data through the pulse fields optical transmission methods have advantages. Therefore we will be using a data transmission link which employs a modulated laser beam technique. This system has been developed by the Telemetry and Range Section of the RAE, with parameters suited to our particular requirement. By this means, the recording equipment may now be moved to a position outside the pulse field, and therefore the equipment within the aircraft can now be reduced to a minimum.

10 When this work has been completed we will be able to investigate the EMP interference problem in small aircraft as affected by the environment now considered appropriate.

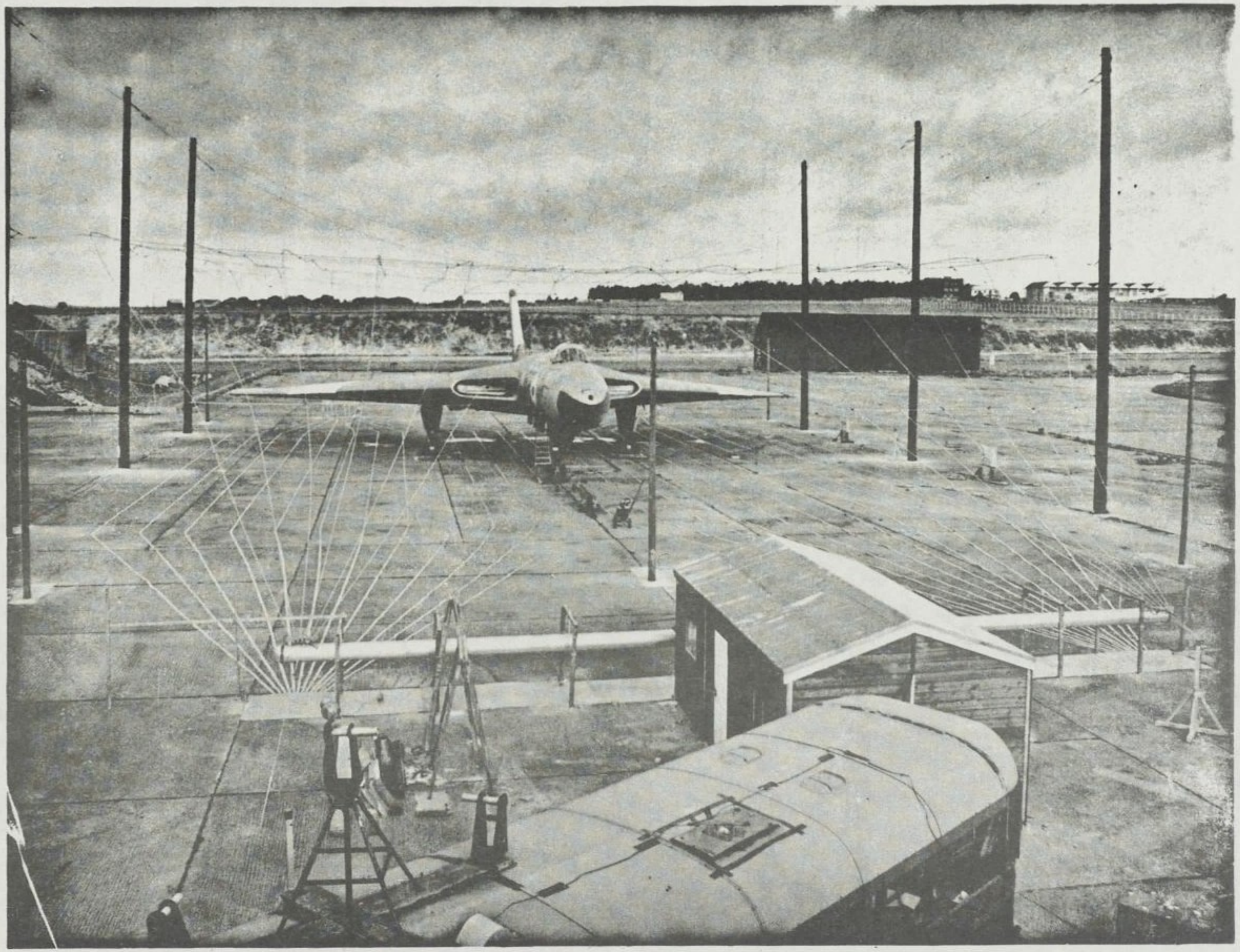


Fig. 1.

## AWRE Programme of Work - Part 1

J D Davies (AWRE)

## 1 INTRODUCTION

Although the general object of today's symposium is one of up-dating information supplied at the symposium last year, it is necessary in talking about the programme of work at AWRE and what has been learnt from it, to go back about two years when the Weapon Effects Study Group under the chairmanship of Dr Panton first tasked AWRE with the assessment of the response of specific military equipments to nuclear effects, namely blast, thermal, nuclear radiation (neutrons and gamma rays) and EMP (electromagnetic pulse). Because, in general terms, blast and thermal responses of targets are topics of long standing on which a good deal of experimental data and design expertise exist, the emphasis of the AWRE programme, particularly in terms of effort, has been on the nuclear radiation and EMP side. In fact you will find that this presentation is also biassed towards nuclear radiation and EMP response. The lessons learned from the EMP studies will be covered by Mr K Norman after I have finished. But I would like to stress that from the concept of Balanced Hardening the study of the blast and thermal response of targets is as important as the study of nuclear radiation and EMP response.

## 2 DETAILED PROGRAMME

The Table in Figure 1 shows details of the programme undertaken by AWRE. I have shown FACE because, although the assessment to neutrons and gammas was carried out under the auspices of DASA (Defense Atomic Support Agency) by the American firm of Systems, Science & Software, AWRE were tasked with underwriting the US report, collaborating with the designers on the system survivability, and in recommending further work arising from the initial study, and in fact demanded some considerable AWRE effort for several months.

The table is presented in the chronological order in which the various equipments were added to the programme, with the exception of the PRC 350 Clansman man pack radio which was the last and fairly recent addition.

Although with this last exception the programme has been in existence for about two years the activities are not yet all completed. This may be rather disturbing to those of you who might interpret this as being another delay in development programmes of new equipment. There are several reasons for this long time, namely:-

(a) AWRE staff had to gain expertise, establish measurement techniques, and test facilities.

(b) Non-availability of hardware both piece-part and complete assemblies.

(c) In many cases no active design team available to discuss design criteria.

I therefore do not consider that the time scale should be taken as a typical example for assessing the additional time involved in the development of hardened equipment. It should be noted that all the equipment studied to date is military.

## 3 THE ENVIRONMENT

All the equipments being studied are operated or carried by individuals or crews and it is therefore reasonable to relate the survival of the equipment to the survival of the men associated with it. The chosen casualty levels for men are:-

(a) a radiation dose of 3,000 rad which is assumed to cause 50% casualties within 1 hour;

(b) the translation velocity due to blast which would lead to 50% casualties for prone men in the open.

Following the process outlined by Lt Col D. Williams this morning to arrive at balanced hardening criteria for the spectrum of yields envisaged in the Army scenario the environment used in the assessments is shown in Figure 2. This is intended to give the order of the parameters and of course the blast environment and thermal environment require statements on peak dynamic pressure, overpressure impulse, and time of maximum thermal flux intensity to completely define them, as elaborated in the talk by Mr Greenhalgh. The EMP data is also not complete. The two figures for blast refer to:-

(1) soft or lightly armoured wheeled vehicles and

(2) lightly armoured tracked vehicles.

## 4 METHOD OF BLAST, THERMAL AND NUCLEAR RADIATION ASSESSMENT

The approach is common for the three environments, ie theoretical analysis and experimental data from simulators. In the thermal field the assessments are based on the extrapolation of experimental results of the response of similar equipment (similar physical construction) exposed in the nuclear test Operational Buffalo Some experimental testing of new materials, ie aerial insulators and ZB 298 aerial cover material is being carried out.

The study of the effect of neutrons and gammas (generally referred to as TREE - Transient Radiation Effects on Electronics) requires a fairly rigorous analysis of the circuit behaviour under radiation conditions using information derived from measurements made on components during or after radiation. At the 3,000 rad level semiconductors are the susceptible items. Neutrons cause permanent degradation, ie reduction in current gain and the gamma rays cause ionisation and hence unwanted transient currents, that in some circuits can lead to permanent damage eg burn out. In some instances the analysis of circuits (using desk calculations) is very tedious and it is necessary to resort to computer aided analysis using such codes as CIRCUS or TRAC.

Figure 3 is the circuit diagram of an oscillator circuit that I am assured is extremely difficult to analyse by hand and Figure 4 gives the CIRCUS solution requiring about 1 hour programming time and 20 minutes computing time. One is able to predict the behaviour of the system to neutrons and gammas by analysis and a subsequent system test is carried out to confirm the prediction.

## 5 RESULTS OR WHAT WE HAVE LEARNED

AWRE staff have obviously learned a lot about ways and means of tackling such studies but you are no doubt more interested in what has been learned about the behaviour of equipment in a nuclear environment. I therefore will summarise what I consider are the salient features that have emerged so far.

### Blast

Other than ZB 298 all studies are completed and reported. The C45 and C45/BID 150 mounted in a Landrover becomes very vulnerable particularly in the side orientation due to the blast causing the vehicle to overturn several times, resulting in damage to whip aerials, aerial tuning unit. The equipment itself suffers secondary damage arising from the impacting of loose units and tool boxes in the vehicle acting as missiles. When mounted in an Armoured Personnel Carrier (APC) the vehicle slides but does not overturn. The blast distorts the top entry hatches and causes them to spring their latches allowing the blast to enter and cause secondary damage as above to equipment and personnel. The whip aerial will also lose some of its sections.

Bruin system equipment in APCs is similarly affected and in addition some of the commercial equipment is not as robustly designed as the military designed equipment and dishing of the thinner gauge panels and possible damage to the contents is expected. The behaviour of the 'B( vehicles (transportable box containers mounted on trucks with a flat platform) is similar to the Landrover; they are easily overturned impacting the ground with considerable force and it is considered that the contents will not survive. Tearing of power leads from the vehicles could also constitute a fire risk. The 40 ft telescopic mast will topple and needs extra guying to prevent this. The C50 and C70 aerials will be permanently twisted.

The man pack whip and the vehicle whip aerials of the Clansman system are satisfactory, but the study has shown some limitations in the design of the ground station aerials, masts and elevated aerials. As these are still in the design and development phase it is expected that these limitations can be overcome.

To summarise, many military vehicles are particularly vulnerable toblast and to ensure survival of internal equipment it is necessary to improve the anchoring of all items carried inside. AWRE Foulness, who have carried out these blast studies have issued papers making recommendations for improving the resistance of vehicles to blast.

### Thermal

The designs of many of these equipments had benefited from the Operation Buffalo trial and no weaknesses have been so far exposed. Results of testing of aerial insulators and ZB 298 aerial protection material are still awaited.

### TREE

The FACE analysis predicted that the computer would be upset by gamma rates as low as $5 \times 10^5$ rad(Si)/s (at about 1 km from 1 kton) whereas the threat level is $2 \times 10^9$ rad(Si)/s (at about 0.5 km from 1 kton). The upset is disruption of the computer main store causing corruption of data without operator knowledge. The Power Supply Unit may fail at a neutron fluence of $10^{11}$ n/cm$^2$ (1 MeV equivalent) and the Sense Amplifier may have problems at $10^{12}$ n/cm$^2$.

Resulting from the FACE study, a contract has now been placed by RARDE Fort Halstead with Marconi Space and Defence Systems, Frimley to modify one FACE equipment to ensure system survivability up to the nuclear radiation threat level. The problem of corruption of data can be overcome by the incorporation of a radiation detector that alerts the operator that the equipment has been irradiated. Resetting and reloading is then required and this is acceptable operationally. This is a type of circumvention.

<u>The C45 No:1</u> being a design incorporating thermionic valves (less susceptible than transistors) was not analysed but exposed to the radiation output from the pulsed reactor VIPER. The set functioned satisfactorily after exposure to pulses simulating the threat environment. To achieve the necessary 3,000 rad dose of neutrons the equipment was exposed several times in the reactor, with intervals of about 2 weeks between each test. The analysis of the <u>C45 No:3 and the BID 150</u> speech security equipment and power supply unit has been completed and a report (WEAT/150/1M) circulated. This predicts that there appear to be no severe problems due to the gamma pulse. The transient currents will cause millisecond perturbations which should not create any problem in a communication system which already has to cope with bursts of noise. It may cause an alarm circuit to operate which the operator will re-set. There is a high probability that the Transistorised Power Unit under worst case conditions will fail due to neutron degradation of the power transistors 29225 - in particular its ability to start if switched on after irradiation.

The analysis of the BID 200 system for use with a radio link has been completed and reported (WEAT/200/1W). As with the BID 150 system the transients due to gamma will cause noise which is acceptable in general except that in the Radio Reconstitutor Unit there is a high probability that the levels of photocurrent that can flow will be damaging. Testing is necessary to confirm this. In addition the Power Supply Unit is particularly vulnerable to neutrons. The +12 volt regulated supply uses a CV 73245 and a CV 7083 whose gains after irradiation will be such that they can supply a maximum of +10 volts at 250 mA instead of +12 volts at 300 mA. The failure level is $7 \times 10^{11}$ n/cm$^2$. This line is used as a reference voltage for several other lines, ie -24V, -9V and -2.8V. Therefore all regulated supplies will be upset with serious consequences on the system performance.

The analysis of ZB 298 is not yet complete but preliminary results suggest that there are unlikely to be any problems associated with the gamma pulse, but that there is a possibility of neutrons affecting the power units, although the increased use of feed back in the circuits has been beneficial.

## 6 R AND D WORK

Finally I would like to acquaint you with a programme of work on the hardening of monolithic bi-polar Integrated Circuits being conducted jointly by the GEC Co, Hirst Laboratory, Wembly and AWRE, on a CVD contract. The aim of this work is to develop the technology required to produce dielectrically isolated IC's. Dielectric isolation eliminates the large collector-substrate junction currents arising from ionising effects in diode-isolated IC's and reduces the possibility of "latch-up" due to the four layer PNPN paths (see Figure 5). Latch-up is a condition where the amplitude of the current that flows is limited only by the supply impedance, and persists until the supply is interrupted. The programme started in August of this year (1970) and it is planned to have applied the new technology developed in this programme to a typical circuit to demonstrate its capabilities in two years time.

## PROGRAMME (W.E.S.G.)

| EQUIPMENT | DESCRIPTION | n & Y | THER-MAL | BLAST | E.M.P. |
|---|---|---|---|---|---|
| FACE | MOBILE DIGITAL COMPUTING SYSTEM, NORMALLY MOUNTED IN AN A.P.C. | U.S. ✓ | | | ✓ |
| C45 No. 1 | GENERAL PURPOSE V.H.F SET (THERMIONIC VALVES) | ✓ | ✓ | ✓ | ✓ |
| C 45 No. 3<br>BID 150<br>(a) LANDROVER<br>(b) A.P.C. | ARTILLERY COMMAND V.H.F SET WITH SPEECH SECURITY BOX | ✓ | ✓ | ✓ | ✓ |
| BRUIN | MOBILE TRUNK COMMUNICATION SYSTEM | ✓ | ✓ | | ✓ |
| BID 200<br>(a) A.P.C.<br>(b) 'B' VEHICLES | AERIALS (1) 40ft TELESCOPIC MAST<br>(2) C50 ANTENNA<br>(3) C70 ANTENNA | | | ✓ | |
| CLANSMAN | HF/VHF RADIO SYSTEMS | | | | |
| (1) ANTENNAE<br>(2) PRC 350 | MANPACK | ✓ | ✓ | ✓ | ✓ |
| ZB 298 | INFANTRY SURVEILLANCE RADAR | ✓ | ✓ | ✓ | ✓ |

FIGURE 1

## ENVIRONMENTS

| | |
|---|---|
| BLAST | (1) 8 psi (2) 14 psi |
| THERMAL | 50 cal/$cm^2$ |
| NEUTRON | 3000 rad (tissue) approx $2 \times 10^{12}$ n/$cm^2$ |
| GAMMA DOSE | 2000 rad (tissue) |
| GAMMA PEAK RATE | $4 \times 10^9$ rad/sec (Silicon) |
| EMP | 50 kV/metre<br>125 amp/metre |

Figure 2

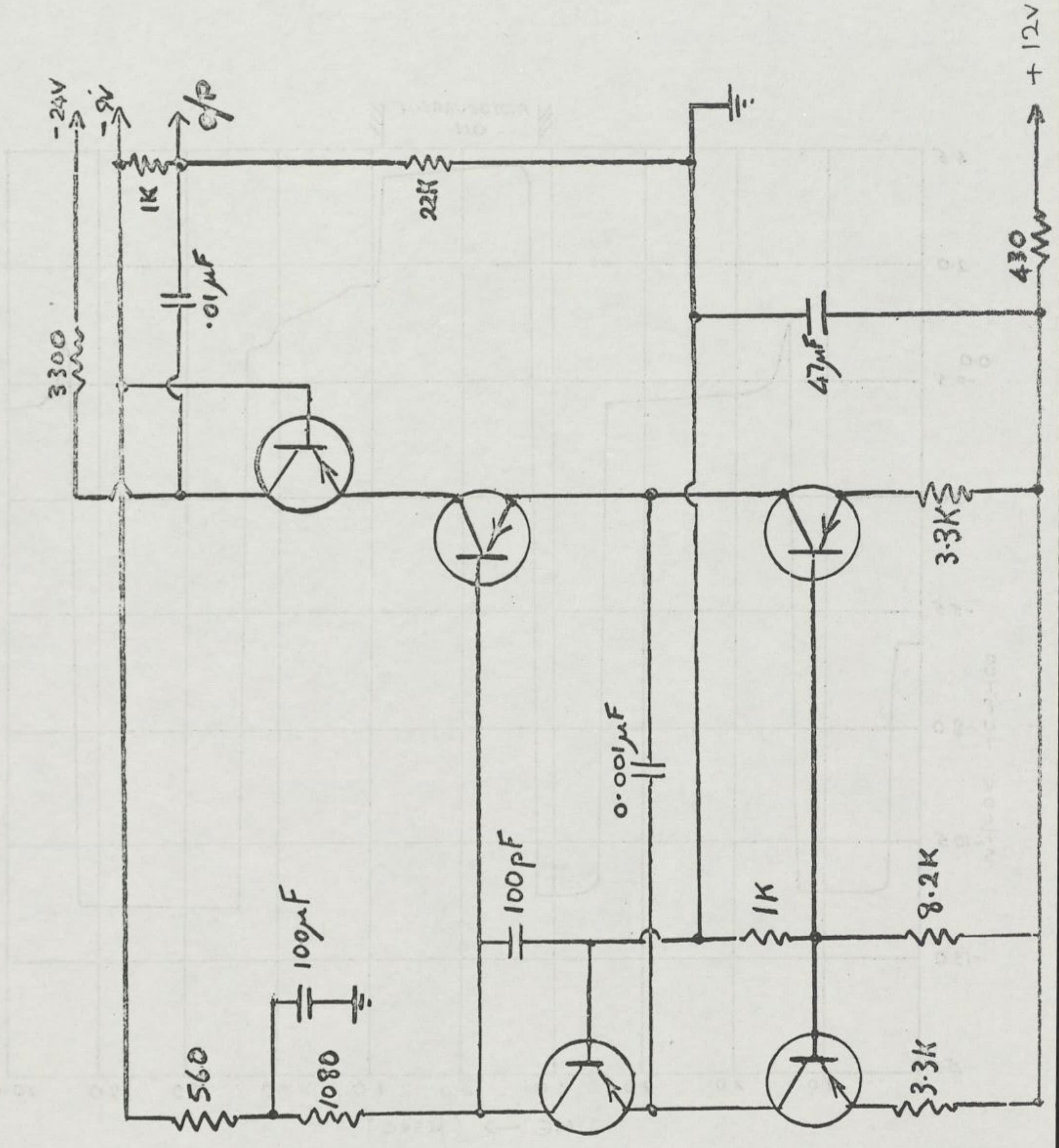

-24V
-9V
O/P
1K
22K
3300
·01μF
47μF
430
+ 12V
3·3K
0·001μF
100pF
100μF
560
1080
1K
8·2K
3·3K

FIGURE 3

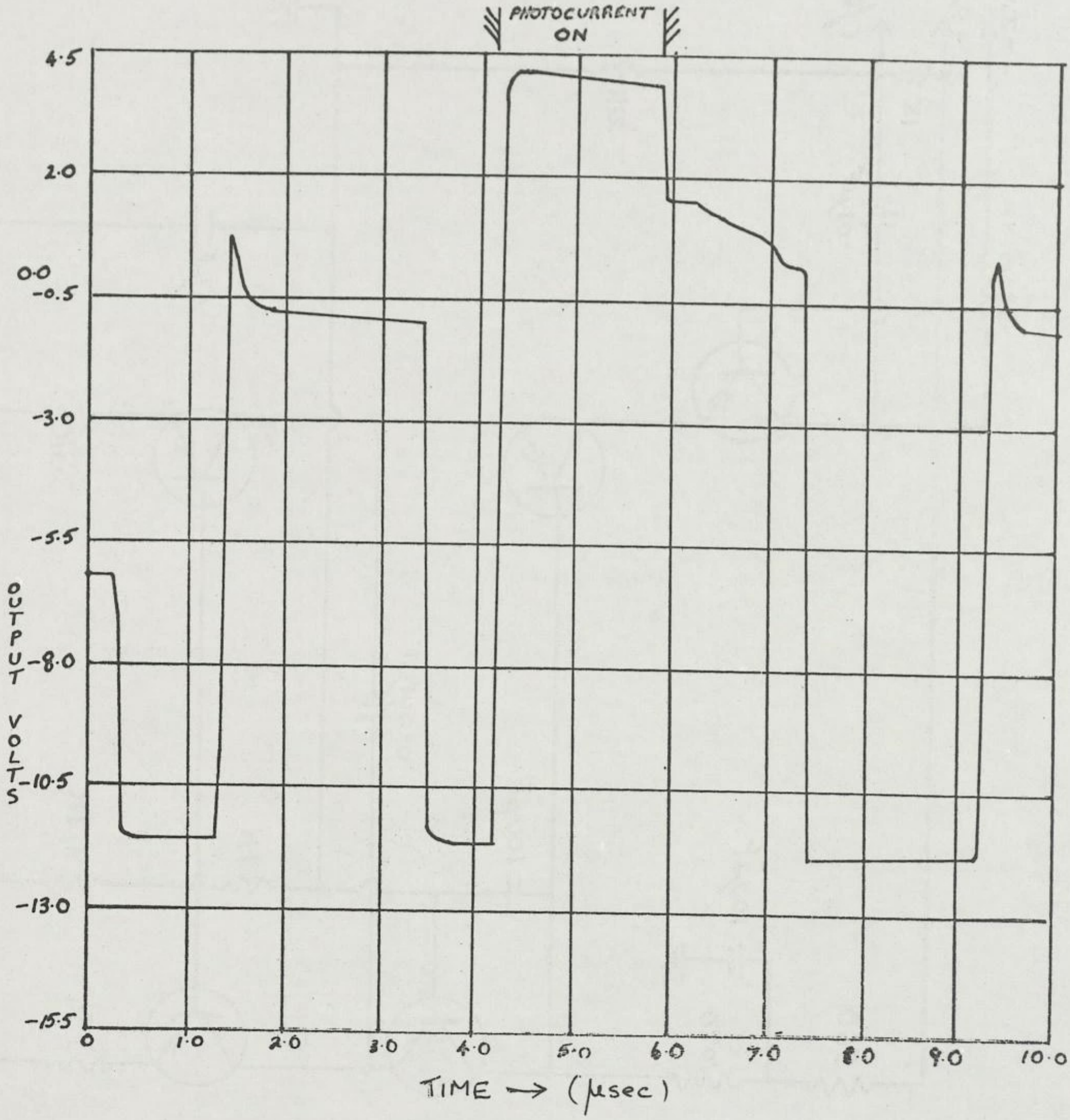
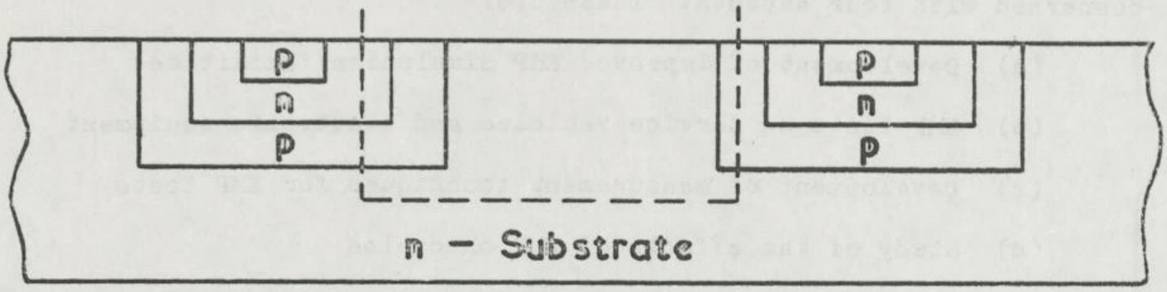
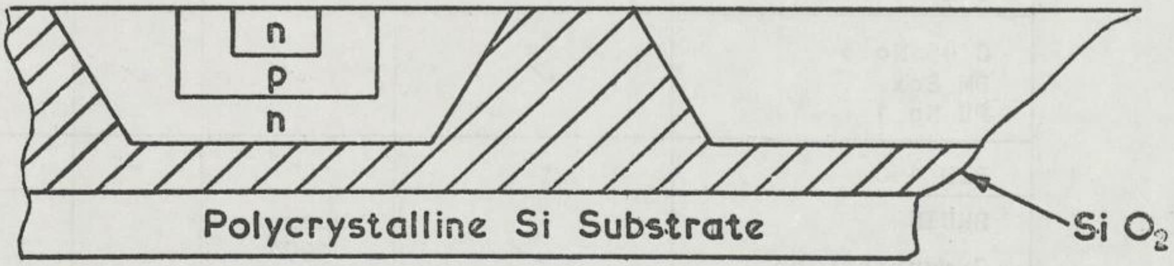

PHOTOCURRENT ON
4.5
2.0
0.0
-0.5
-3.0
-5.5
-8.0
-10.5
-13.0
-15.5
OUTPUT VOLTS
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
TIME → (μsec)

FIGURE 4



DIODE ISOLATION



DIELECTRIC ISOLATION

FIGURE 5

There have been many proposals for evaluating the performance of Service electronic equipment in EMP conditions. Exposure of apparatus and vehicles in a simulated EMP threat field environment was favoured as it avoided the lengthy measurement, analysis and synthesis required by continuous wave tests or low level pulse field tests. Furthermore, it was relevant to have a typical equipment fully operational during the EMP test exposures to judge its performance. Following EMP testing the equipment could be tested to specification to establish the existence of any faults. This approach to EMP testing of equipment in facilities is valid if the typical equipment layout is contained within the transmission line without sensibly altering the pulse field conditions. Although some of the single vehicles tested in PETS 1 facility had relatively high dimensions, such as the FV 432 shown in Figure 1, their effect on the system was understood.

The equipment so far tested in PETS 1 at AWRE has included a digitised computer (FACE) in an armoured vehicle and communications equipment operating in the VHF, HF, MF ranges either mounted in soft-skinned vehicles or as isolated units with self contained loop or whip antennae. Tests were performed using single models of endo-atmospheric and exo-atmospheric pulse fields up to 50 kV/m field strength with corresponding 130 Amp/m H-fields associated with the plane wave condition. The computer was shielded from the primary field although the apertures were provided with chemical seals only. The communications equipment was fully exposed to the primary simulator field except for some slight reduction in the rear of a Landrover vehicle near the equipment under test.

Where equipment is shielded from the primary EMP fields, secondary fields, created by leakages or the intrusion of current bearing elements, can be significant in inducing interference signals particularly on cable systems. In the case of the FACE computer equipment an antenna lead passed a current of several hundred amps into the vehicle contributing to interference levels which caused temporary computer malfunction. Other temporary faults experienced were corruption of computer variable data, power switching down, and console display faults.

During these tests at field strength levels between 30 kV and 50 kV/m, currents up to 20 amp peak were observed in interconnecting cable looms in the computer system. Although RFI precautions to improve computer shielding and reduce circulating earth currents had been included in this equipment design, there were still difficulties under these high field strength conditions.

The faults observed on this equipment could be corrected by procedural methods assuming that the variable data had been recorded on punched tape for re-entry after indication of EMP exposure.

It was expected that on-line communication equipment would be vulnerable only to permanent or semi-permanent damage as temporary faults would only occur for periods short compared with speech and telegraph rates. Even in circuits using digital techniques of modulation, temporary faults might produce no apparent malfunction if self-checking and resetting circuits were included in the system. Semi-permanent effects such as power stabilizer cut out could cause temporary loss of communication until the circuit was reset. Permanent damage might be expected through coupled antenna and input cable currents reaching the sensitive input circuits of radio sets.

In practice large currents proportional to the time derivative of the electric field were measured on whip antennae. In one example the high pulse current (70 amps peak within 100 nS) did not affect the C45 radio set, due possibly to the filtering effect of the tuning unit beneath the antennae.

Further input cables passed within the vehicle's metal body and, due to the cable layout, cable currents at the radio input were lower at 10 amps peak. The C45/BID150 equipment employing valves in its radio frequency circuits survived 88 exposures in simulated EMP pulse fields. Solid state equipment in this system mounted in well-shielded boxes received no apparent permanent damage. Cables connecting these units formed mainly small area loops passing coupled currents not greater than 10 amps peak. Pulse current on the tubular steel tilt support was 27-30 amps peak.

Other tests with radio communications equipment have produced permanent damage to semiconductor input circuits. These particular effects have been observed both with vertical whip antennae and ferrite core multi-turn loop antennae connected to the input circuit when exposed to exo-atmospheric model fields in PETS 1. It is felt that internal ferrite antennae are less troublesome than short whip antennae. Semiconductor pulse damage data has indicated that some low power transistors are vulnerable to pulse energies of 10-50 micro-Joules in the reverse base-emitter region. There appears to be a general problem area at input circuits where several micro-Joules of energy appearing at semiconductor junctions could cause permanent damage.

Not all the radio equipments with semiconductors tested in PETS 1 have suffered permanent damage. Preliminary tests of a compact portable radio unit with a 1 metre whip antenna after exposures to exo-atmospheric and endo-atmospheric model pulse fields at 50 kV/m were encouraging. The engineering of this unit had included some RFI circuits to counter the effects of nearby high power transmitters on its input circuits and these precautions may have provided some protection from antenna coupled currents in the range 15-30 amp peak.

The lessons learned so far from the results of these EMP tests can be summarised as follows:

(1) Internal vehicle fields do not necessarily resemble the primary field and attenuation ratios must be applied with care. For instance fields set up within vehicles show both time derivative and time stretched waveforms.

(2) The theoretical attenuations for screened containers are rarely attainable. The internal environment is more influenced by secondary fields due to leakage through apertures and currents brought in along external cables than by direct field penetration.

(3) Large peak currents (up to 800 amps have been observed) proportional to the rate of change of the electric fields are established in monopole antennae and cables mounted in the plane of the primary electric field.

(4) Equipment cable loops enclosing the magnetic field may pass induced currents proportional to the wave shape of the field.

(5) The ability to survive an EMP exposure is not dependent on any single feature of design in an equipment. Shielded equipment has been affected due to vehicle apertures and field created by intruding cables which are unfiltered. Fully exposed equipments with well-bonded simple boxes have survived possibly due to compact cable layout and by-passing of interference currents through tuning units.

(6) The susceptibility of semiconductor input circuits to coupled energy from EMP fields has been observed. The encouraging performance of one such equipment during exposure may have been partly due to deliberate precautions applied for RFI purposes.

(7) EMP protection to equipment must be considered as a separate task. However much one is tempted to expect that RFI precautions will be sufficient, no guaranteed reliance can be assumed in EMP exposure conditions. There is no doubt some of the RFI precautions form a good basis for EMP protection, but it must be remembered that they are provided to allow for various communication equipments to exist in close proximity and may not provide the broadband transient protection necessary under EMP conditions.

## 2 EMP Measurements

A continuous study of EMP measurement techniques has been carried out at AWRE. A range of electric field magnetic field and pulse current sensors has been developed for use in the test programme. The sensors measure E-field strength from 100-50,000 V/m, H-field strengths to 130 amp/m and cable pulse currents up to 1,000 amp on 2 inch diameter cables. Sensor design has been continually reviewed to take in the changes of predicted EMP field shape.

The problem of extracting data from EMP fields has been approached in several ways. Where large signals are available from sensors at ground level, double screened twin coaxial cable has been used to pass information to a shielded measurement room outside the facility (see Figure 2). For measurements above ground level where cable transmission is not acceptable, a laboratory model optical telemetry system using light diodes and fibre optics has been developed. The system in use can pass a broadband signal to a well screened cabinet just outside the working volume. The sensor amplitude modulates a light diode and after passing along the fibre optic, light signals are demodulated using a photomultiplier to obtain electrical information for display on a high speed oscilloscope.

We have found double screened aluminium boxes with 88 dB E-field and 56 dB H-field peak pulse attenuation useful to contain high speed oscillographic measurement systems operated from internal batteries with invertor supplies.

## 3 The Effects of EMP on Cables

It has been recognised at AWRE that among the most important effects from EMP are those caused by currents flowing along exposed cables. In distributed installations cables may extend up to several kilometres and may interact with the magnetic and electric field in many modes. In certain cases cables may resonate in a dipole mode and in other conditions form transmission line configurations and loops with other cables. From any of these modes large currents may develop with time signatures which are difficult to predict.

A study of EMP cable effects has recently started at AWRE. At this early stage it is not possible to predict the performance of specific cables in defined circumstances except in very simple geometry. However, considerable data have been collected and shortly, predicted calculations will be attempted. It is hoped that practical tests on long cables will be started next year with the commissioning of a large area radiation pulse simulator.

## 4 Conclusion

In the two years since we first started work we have begun to understand some of the problems caused by EMP. A degree of confidence has been gained from this experience, but it is recognised that the greater part of the task lies in the future and there is still much work to be done.

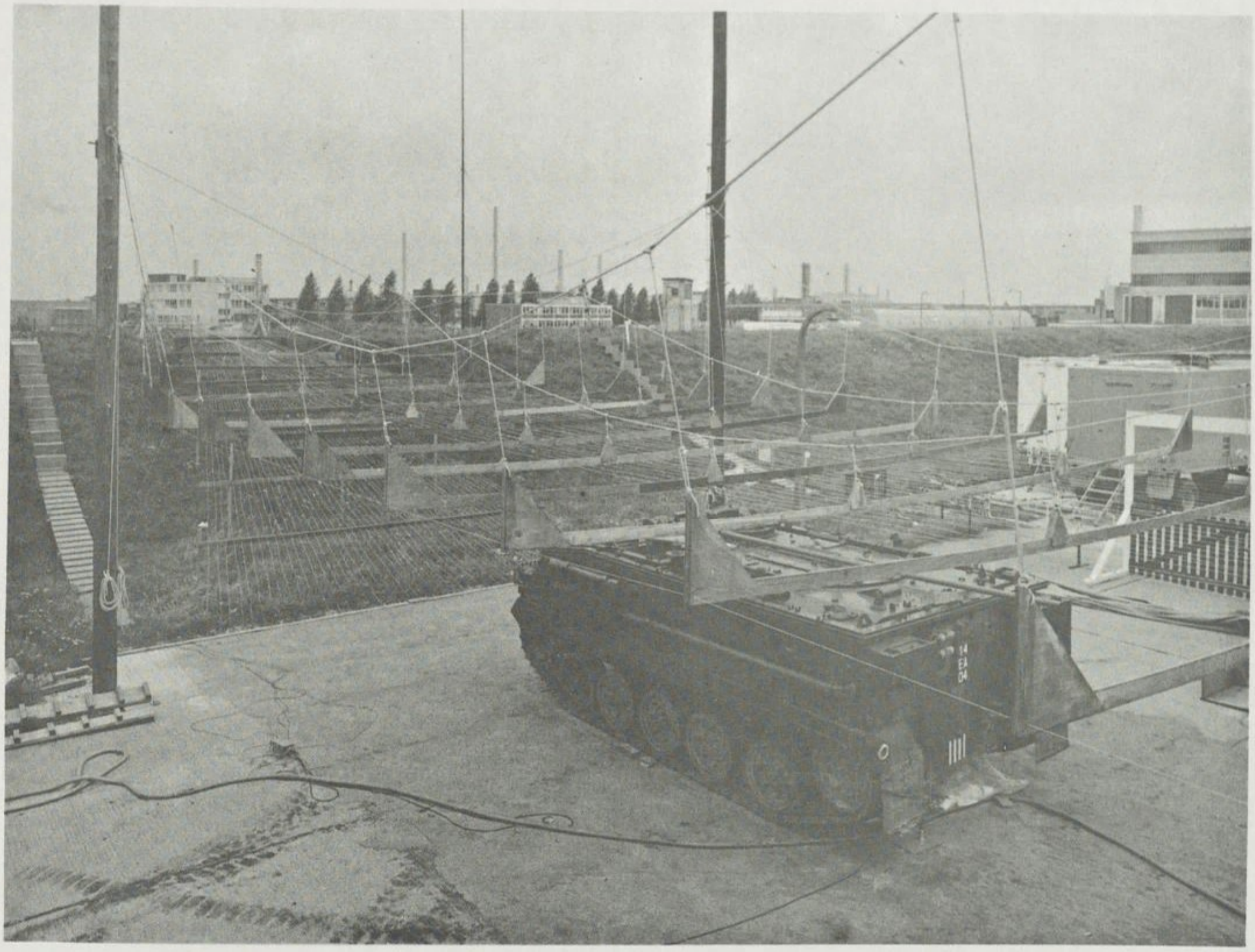


Figure 1

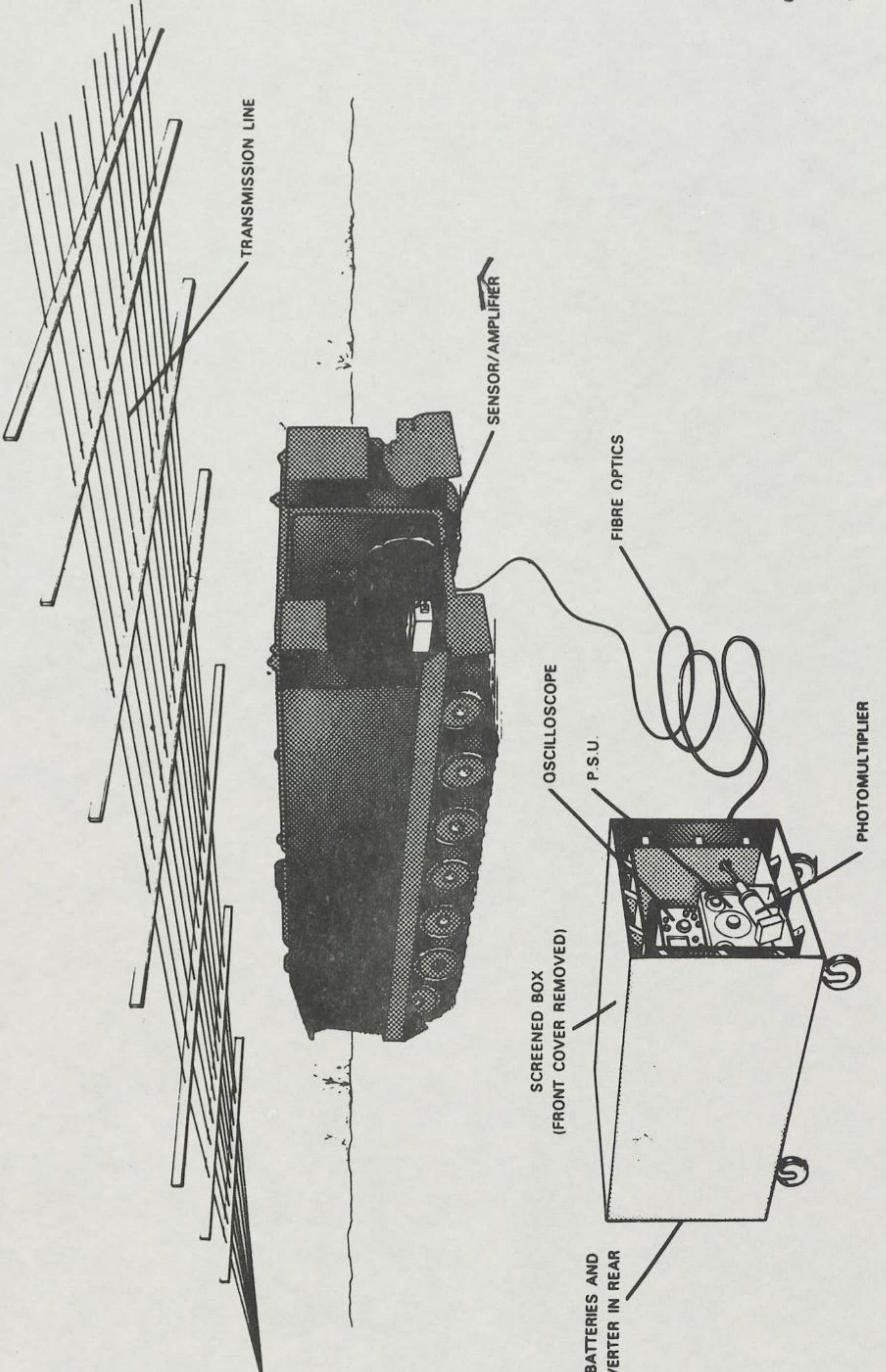


DIAGRAM OF REMOTE EMP MEASURING FACILITY

FIGURE 2

# PROGRAMME OF WORK

## RAE Programme of Work on the Response of Airborne Systems and Aircraft to Nuclear Weapon Effects

P H Reed (RAE)

## 1 INTRODUCTION

At RAE, we are concerned with two aspects of aircraft response to NW effects. Firstly we are responsible for ensuring the safe escape of aircraft which have delivered a nuclear weapon, and secondly we are responsible for providing survivability data to the Services for aircraft subject to a NW effects environment. These aspects concern rotary wing and fixed wing aircraft, airborne avionic systems, airborne weapon systems, and, recently, hovercraft. Consequently we have a widely varied programme of work on hand and planned under the general auspices of the Nuclear Weapon Effects Panel and financed by various MAS HQ Directorates.

In discussing NW effects relative to aircraft and airborne equipments it should be remembered that we are concerned with a very much lower threat level of each effect than the Army and Navy environments.

## 2 EXTRA-MURAL STUDIES

### 2.1 HSA (Brough) Ltd

This is a new study to assess the survivability of the Buccaneer Mk 2. The results from this study should be complete around June 1971, and should prove of wide applicability for modern strike aircraft, eg MRCA, Jaguar, Harrier etc. The trend of the results to date is to considerably reduce previously accepted survivability threat levels of blast and thermal effects. Preliminary examination of the gamma radiation effects on the avionic system indicate that at the $3 \times 10^8$ rads/sec level, most of the systems will be degraded. The extend of the degradation and the effect on the flight safety has not yet been determined. The effect of the EMP has not yet been assessed.

This study is financed by D/RAF (Buccaneer).

### 2.2 Hunting Engineering Ltd

We have a number of studies on HEL financed by DA Arm. Some, such as the examination of thermal radiation enhancement factors due to cloud and ground reflection are fairly basic studies, whereas some which deal with project aircraft escape trajectories following a weapon delivery are more operational in nature.

The aircraft examined by HEL have included Buccaneer, Vulcan, various helicopters, in fact all aircraft which have, or are, associated with nuclear weapon delivery operations.

They have also been assisting RAE in developing a method of presenting NW effects data to aircraft manufacturers to enable them to interpret aircraft specification requirements. However, if the present pattern of specifying the NW effects environment associated with the MRCA is followed in future OR targets, this aspect of HEL work may be deleted.

### 2.3 Future Extra-Mural Studies

During the coming year studies to examine the survivability to NW effects of the Phantom, MRCA, Hovercraft, and Rotary Wing aircraft should commence providing finance is forthcoming from the relevant Project Offices.

## 3 INTRA-MURAL STUDIES

### 3.1 Blast Effects

This year a Gnat aircraft was modified to enable full-scale testing to be conducted in the AWRE, Foulness, shock-tube facility. It was the first time that an aircraft has been tested in this manner under such controlled conditions. The aircraft was fitted with pressure gauges, strain gauges, accelerometers and a cockpit auto-observer to monitor the pilot's instruments. In spite of difficulties developing the test technique, and the loss of most of the strain-gauge array, this experiment was well worth the effort.

The analysis of results is a long task, but the initial results examination has already provided data for several aircraft studies. The final reports associated with this work should appear during the next 6 months. However, structural data, and data on the behaviour of cockpit flight instruments etc using pitot-static sensors has already been supplied to HSA for the Buccaneer study.

### 3.2 Thermal Effects

The problem of obtaining appropriate thermal enhancement factors for aircraft radiation for given conditions of cloud, terrain, and visibility was also examined early this year. We concluded that those then in use were too high, possibly by a factor of 2.5. Consequently we placed a study at HEL to re-examine all the previous literature, data, etc and, if necessary, to recommend revised procedures. This they have done and the result is now being examined in some depth both by RAE and AWRE. If the new procedure is agreed these factors could reduce, for some specific cases of interest, from 5.0 to 1.8. This represents in many cases the difference between survival and aircraft loss.

### 3.3 Electro Magnetic Pulse Effect

With the completion of our 3 m simulator in mid-September this year we have commenced an experimental programme to support our earlier theoretical examination of aircraft avionic system response to this effect.

Once the usual instrumentation difficulties were sufficiently overcome to obtain meaningful data, it quickly became apparent that the aircraft was behaving as a normal dipole or antenna in these electro magnetic fields. It was shown, using various lengths of idealised simulated aircraft hulls, that the hull efficiently received only those frequencies lying a predetermined bandwidth on either side of a resonant frequency based on the hull length. The hull diameter determined the band-width. Thus as for ordinary antenna the length and diameter of the hull defined the frequencies of interest of the EMP electricfield environment.

The magnetic field component on the other hand was found to be very little attenuated at all frequencies up to around 30 MHz. At this frequency we believe the induced skin currents in the hull commence effective reflection of the magnetic field. From this work we believe we can suggest the nature of the electric/magnetic field ratio within the aircraft hull, although not yet the possible vector relationship. Following this work we turned our attention to looking at cable transient signals induced by this modified field within the hull.

An interim paper was produced for the recent TTCP Panel N7 in Canada which appears to have stimulated some useful discussion.

Some 150-200 test runs have now been completed measuring voltage transients in cables within an idealised aircraft hull. This work encourages us to believe that we will achieve our object of developing a model for cable transient signal prediction during the next year, and from this a current injection test technique for system testing. This technique will be based on the BS2G 100 specification technique and hopefully will eventually form an appendix to that specification for aircraft avionic equipments.

However, before we attain this objective we have to further improve the integrity of our test instrumentation for simulator work. We propose to fit a fibre-optic transmission system early in the new year based on a system being developed at SRDE.

### 3.4 Radiation Effects

We have no experimental programme in this field and depend upon data from a number of sources to assist us in advising avionic equipment designers. However, we believe that it is largely up to equipment designers to select components based on the radiation specification for the project since the component manufacturer usually seems to have a good idea of the limitations of their own transistors etc.

A further point is that because of the probable survivability levels of aircraft relative to blast and thermal radiation effects, together with the exposure probability of aircraft to radiation effects it now seems likely that radiation levels specified for aircraft will not exceed $10^7$ rads/sec gamma dose rate.

At this level of threat we anticipate that sensible equipment design appraisal perhaps combined with a mechanical authority restriction on certain components will ensure the aircraft safety. Some degradation in operational efficiency in these hostile environments may have to be accepted although, hopefully, it will prove to be only transitory. The extent of this degradation should emerge from the various aircraft studies now in hand or proposed to commence within the next year.

Hopefully, between the AWRE component irradiation programme, and US data we will manage to advise avionic designers on components to avoid, so that they may achieve $10^7$ rads/sec.

# PROGRAMME OF WORK

## Programme of Work at A and AEE

G F Hocking (A&AEE)

### Introduction

1 The work done at Boscombe Down during the last 2 years was to investigate the EMP effects, mainly on one aircraft, using the facilities we have already described.

2 The experience we have was gained from a trial whose object was not an exhaustive investigation into every conceivable aspect of EMP effects - that would indeed be a formidable task - but to investigate particular systems whose failure could hazard the specified aircraft. Although the work was aimed at a particular aeroplane the experience gained has proved to be of value in relation to other aircraft, and the expertise developed will enable us to carry out future investigations more rapidly.

### Experience and Programme

3 We consider that when the EMP interacts with the aircraft 2 principal phenomena occur. One is that the pulse fields intrude into the airframe in a distorted and attenuated form due to electrical discontinuities in the airframe and skin, and the other is that oscillatory circulating currents are generated in the airframe - skin currents. The dominant effect is considered to be the coupling between these skin currents and the aircraft wiring, which is largely installed close to the skin or structure. The principal couplings are:-

a Inductive coupling between the skin currents and the wiring

b Capacitive couplings with the electric field.

Secondary couplings also occur between adjacent cables due to their carrying current caused by the principal couplings.

4 Currents flowing in an airframe strut were found to be oscillatory, with a dominant frequency apparently corresponding to the dipole response of the aircraft as a whole. Harmonics are also excited and the relevant phase responses give rise to the characteristic wave forms shown by the oscillograms (Figure 1). The oscillatory response obtained for a large aircraft was about 6 MHz and a smaller one about 11 MHz. These figures corresponding to the half-wave dimension of the aircraft concerned. Typical oscillograms show that oscillatory voltages and currents were induced into the aircraft wiring. The voltage measured at equipment terminals varied from a few volts to a few tens of volts according to the impedance of the circuit being monitored.

5 We saw no evidence of a significant low frequency or long term response. With the oscilloscope set for 5 μs per division (a very slow speed in this application) the oscillatory trace was all crowded into the first division, with a base line for a further 40 μs.

6 Estimates made from oscillograms of the response on some aircraft circuits have indicated that the energy content of the transient is less than a micro joule.

7 Measurements were also made with the aircraft turned through 180°. Little difference in the energy content of the results was seen. This of course does not rule out variation due to other orientations; however, these were unable to be checked due to the physical limitations of the rig and aircraft.

8 The voltage transients recorded as caused by our particular pulse, were less onerous than most switching induced transients, particularly in respect of their energy content; consequently any equipment which will accept an electrical supply as specified in the aircraft specification BS 2G 100 should not be troubled by the effects of EMP. The circuits need to be checked against the environment of the pulse now postulated, for a faster rising pulse will increase the amplitude of the response. However, the transient excursion should still be well within the limitations of BS 2G 100 even though the response is perhaps, 3 to 4 times greater. Further, it is evident that there is insufficient energy in the response to damage electro-mechanical devices such as relays or contactors and, as their operation time is many orders slower than the transient; they will not malfunction.

9 We consider that, as the time constants of analogue systems are relatively long, errors due to the half microsecond transient as caused by our simulator are unlikely.

10 For digital systems, interference may occur although at this stage we have no evidence either way, however our work suggests that any problem arising would be alleviated by adopting such techniques as the use of screened twisted pair cable for signal writing, by using a mark space ratio for pulsed signals which is compatable with the time of the EMP transient interference, and further by adopting a signal level of tens of volts rather than volts wherever practicable.

11 In addition, a study of the earthing problems for each particular system may prove necessary.

## Future Work

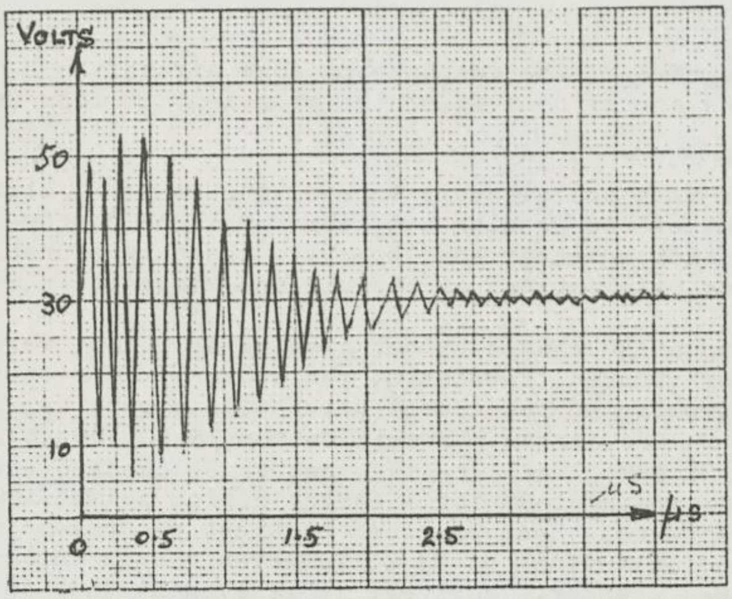
12 As to our future work, we intend to expose a complete aircraft fitted with its basically analogue nav-attack system to a dynamic EMP interference test early in the new year.

13 A small digital system is to be simulated in an aircraft ahd subjected to the pulse in attempt to establish a feel for its vulnerability.

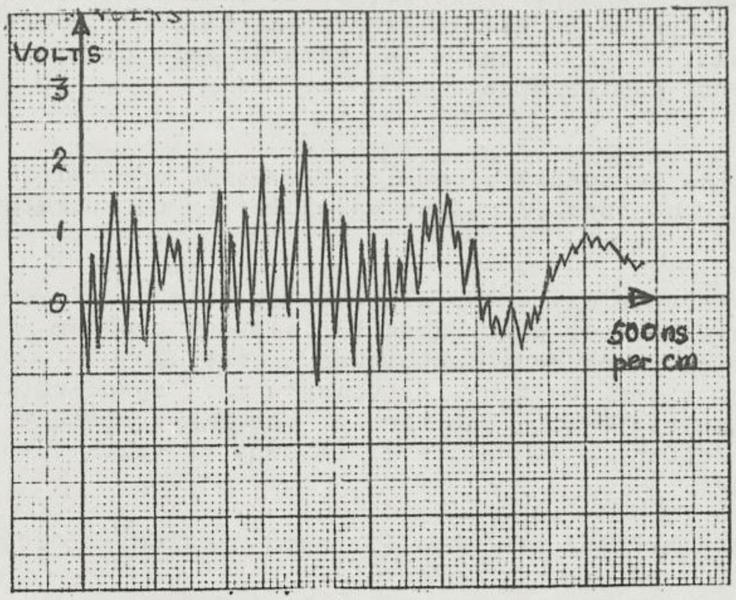
14 The results obtained on the Vulcan aircraft are to be reviewed in the light of the pulse shape now postulated.

15 Some additional measurements of induced cable surrents will be made before the rig is dismantled for the incorporation of the changes necessary to produce the revised pulse shape. Our new instrumentation equipment and facility will also be installed during this period.

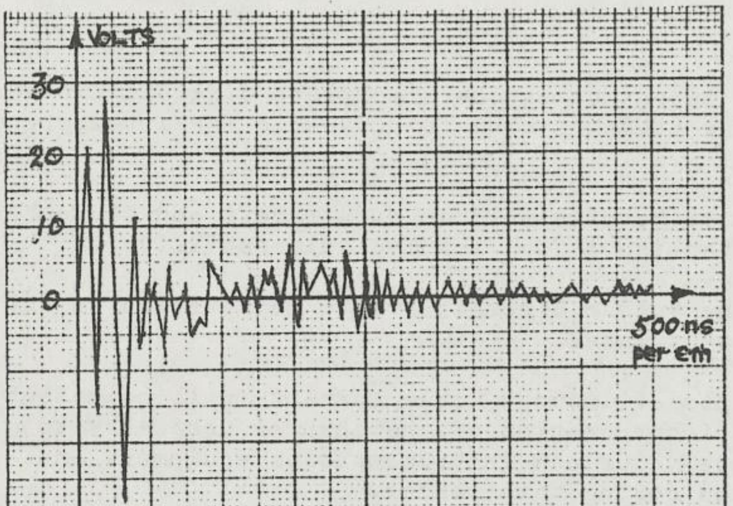
16 It is hoped to complete these changes by late next summer, and from that date we will be able to continue test work in support of future aircraft design, and to simulate interference tests for aircraft and their equipments.



Pulse 2 kV/metre
10 metre HORIZONTAL LEAD
IN BOMB BAY (LEAD OPEN
CIRCUIT)



Pulse 2 kV/metre
MEASURED IN FRONT OF
BOMB BAY.
(APPROX DC RESISTANCE OF
10Ω)



Pulse 30 kV/metre
TRIGGER/CATHODE TRACE IN
'LIVE' GENERATOR CONTROL
SWITCHBOX.

FIGURE 1

## PROGRAMME OF WORK

### The Effect of EMP on Shipborne Electronic Systems

H Walker (ASWE)

1. The literature provides little or no information on the observed effects of EMP on shipborne electronic systems and when one looks at the number and variety of aerials which may be found on a ship's superstructure it is apparent that full-scale EMP simulation is impracticable. Figure 1 was taken from the flight deck of HMS ARK ROYAL and in addition to the many aerials shown the funnel and mainmast are also used as HF communication aerials. The mass of the ship itself will have a pronounced disturbing effect on the EMP fields and we can therefore only indicate, by making many assumptions, which shipborne systems are most likely to be affected by EMP.

2. The most likely nuclear threat to naval surface forces is the low-altitude burst of weapons of a few kilotons but the exo-atmospheric high-yield burst with its widespread EMP fields cannot be ignored.

3. In order to assess the effects we need to know the EMP spectral energy density distribution and Figures 2 and 3 by Dinger in the US show this in Joules per square metre at the earth's surface from a multi-megaton exo-atmospheric burst, and secondly at a range of 1.5 Km from a 250 kT surface burst. Although the total energy density from the surface burst is much higher than from the exo-atmospheric burst, in both cases about 98% of the total energy is contained in the HF and lower frequency bands with the level falling off steeply at higher frequencies. Since aerials in these lower frequency bands are generally physically large they will tend to collect much more EMP energy than those at higher frequencies.

4. The magnitude of the EMP increases very rapidly in the proximity of the source region and it is necessary to consider the other weapon outputs since there is no point in attempting to harden against EMP when other weapon effects are more devastating. Figure 4 shows the approximate boundaries of the EMP regions together with contours of other weapon effects for weapon yield and range from a surface burst. For yields up to about 20 kT both radiation dose and EMP increase very rapidly as range closes from the 3.5 $lb/in^2$ to the 10 $lb/in^2$ peak overpressure contour, and the radiation dose is the limiting factor. At higher yields the EMP tends to remain fairly constant along the overpressure contours, the radiation dose decreases but the level of thermal radiation increases.

5. We have recently obtained some experimental evidence of EMP damage. Tests on a submarine VLF/LF receiving aerial and pre-amplifier at AWRE have shown that the front-end transistor was liable to burn out when subjected to the simulated EMP from an exo-atmospheric burst. In this case the effective aperture of the aerial was very small, about $10^{-4}$ sq metre, and reasonable agreement has been reached between laboratory measurements of the joule energy required to cause burn-out and the estimated EMP energy collected by the aerial and pre-amplifier. Replacement of the

transistor by a nuvistor, a type of sub-miniature valve, is expected to provide an adequate margin of safety since valves are some orders of magnitude more resistant to EMP damage than transistors, but other means of protection are also being investigated.

6. Since the effective aperture of shipborne HF and lower frequency aerials may be as high as several square metres it is highly probable that any transistorised receivers in these bands will be vulnerable, and even the currently fitted valved equipments may be vulnerable under severe EMP conditions.

7. At higher frequencies the smaller aerials and lower EMP energy density ease the situation. The naval VHF communications equipment, used for communicating with merchant ships, is valved and is unlikely to be affected except under the most severe conditions.

8. The only metric naval radar in service is the Type 965 Surveillance Radar which has a large aerial with an aperture of about 30 sq metres, the polarisation being horizontal. Since the EMP electric field from a low-altitude burst is vertically polarised, cross polarisation will reduce the EMP energy collected by about 20 dB. The transmit-receive cells will provide further protection and the pre-amplifier is valved so that it is unlikely that this radar will be affected.

9. Current UHF communications equipments are valved but from 1973 onwards will be replaced by transistorised equipments. Except for secondary and emergency channels common-aerial working is employed, using high-Q filters which will limit the EMP energy getting through to the receivers. Even without these filters initial estimates point to a reasonable margin of safety with the transistorised receivers.

10. Equipments operating at centimetric wavelengths should in general be immune to aerial induced EMP since the cut-off frequency of waveguides will limit the energy getting through to the receiver and transmit-receive cells or other protective devices will give further protection, but equipment malfunction might still occur as a result of direct penetration of the ship's structure by the electric and magnetic fields, or by associated secondary effects.

11. An area of greater uncertainty, requiring further investigation, is the effect of EMP and of nuclear radiation on digital circuits, program and data stores in computers and peripheral equipments.

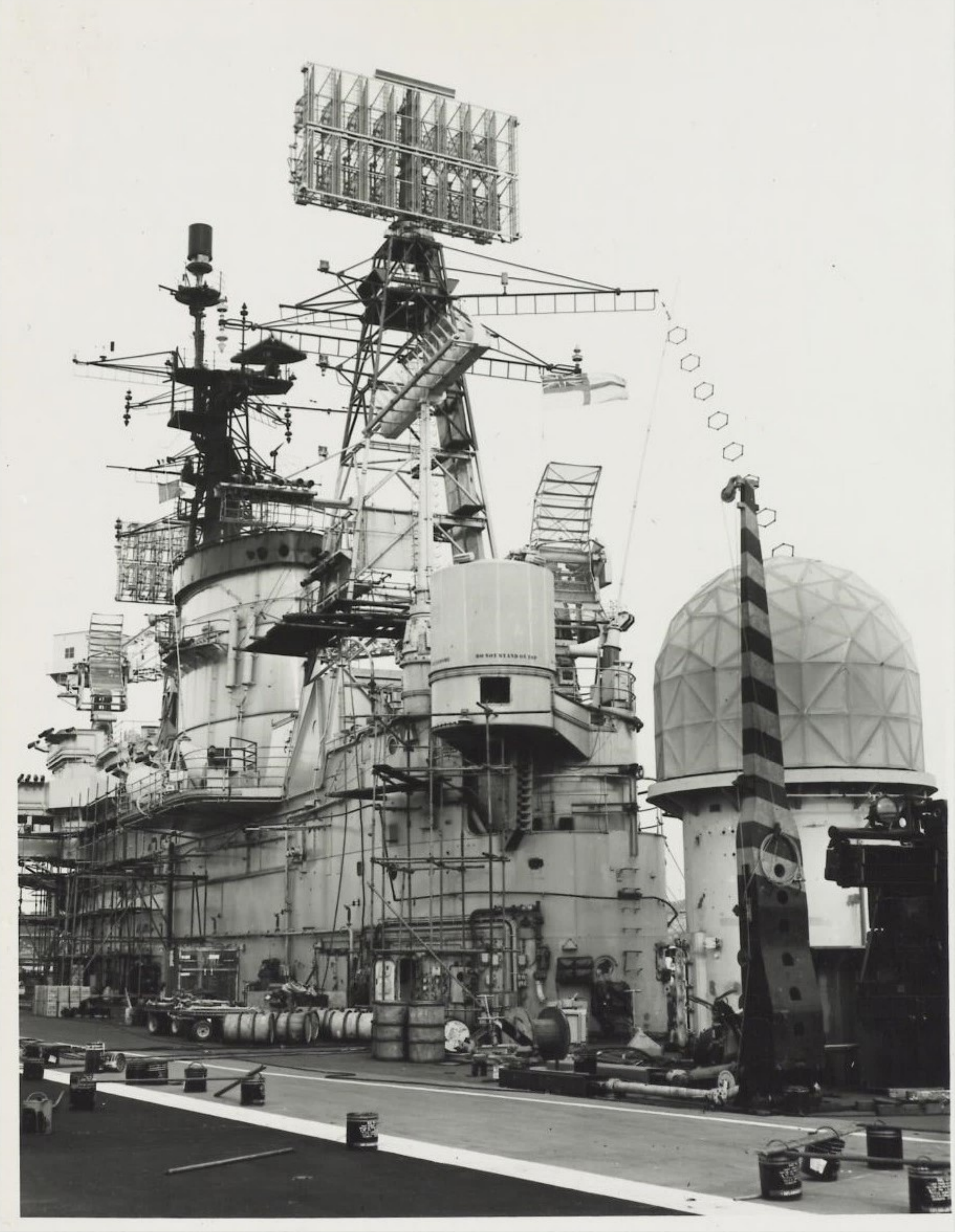
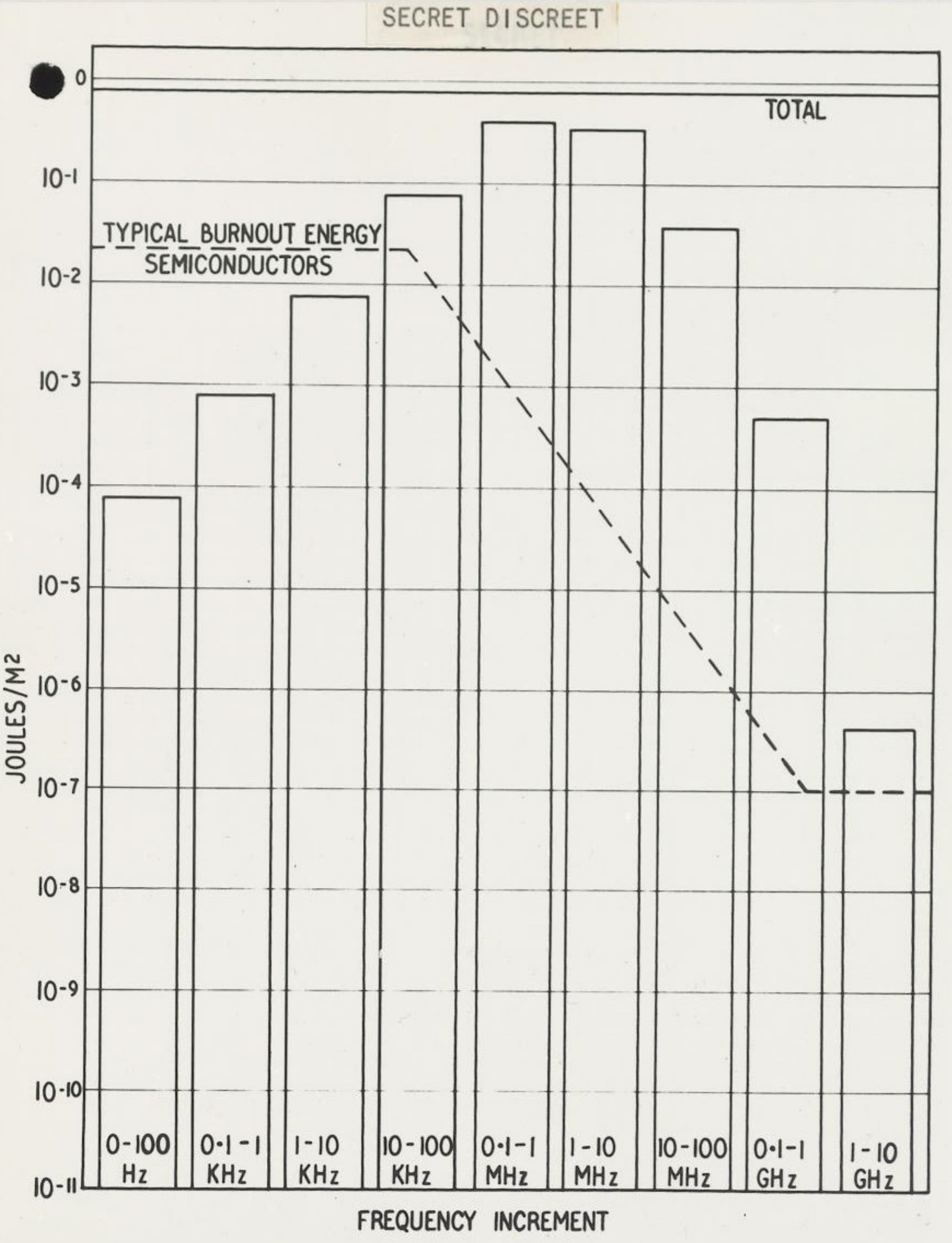


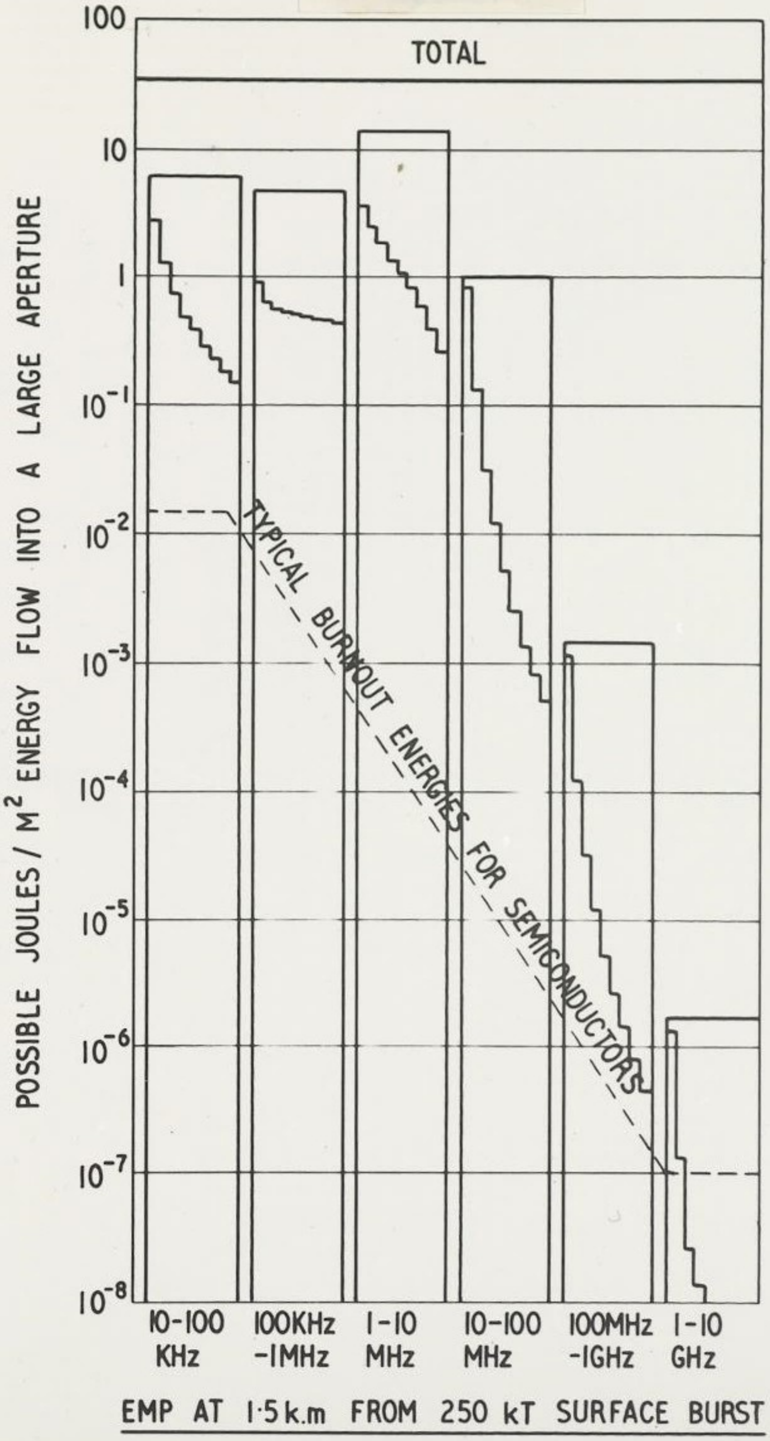
FIGURE 1



EMP FROM EXO - ATMOS. MULTI - MEGATON BURST.

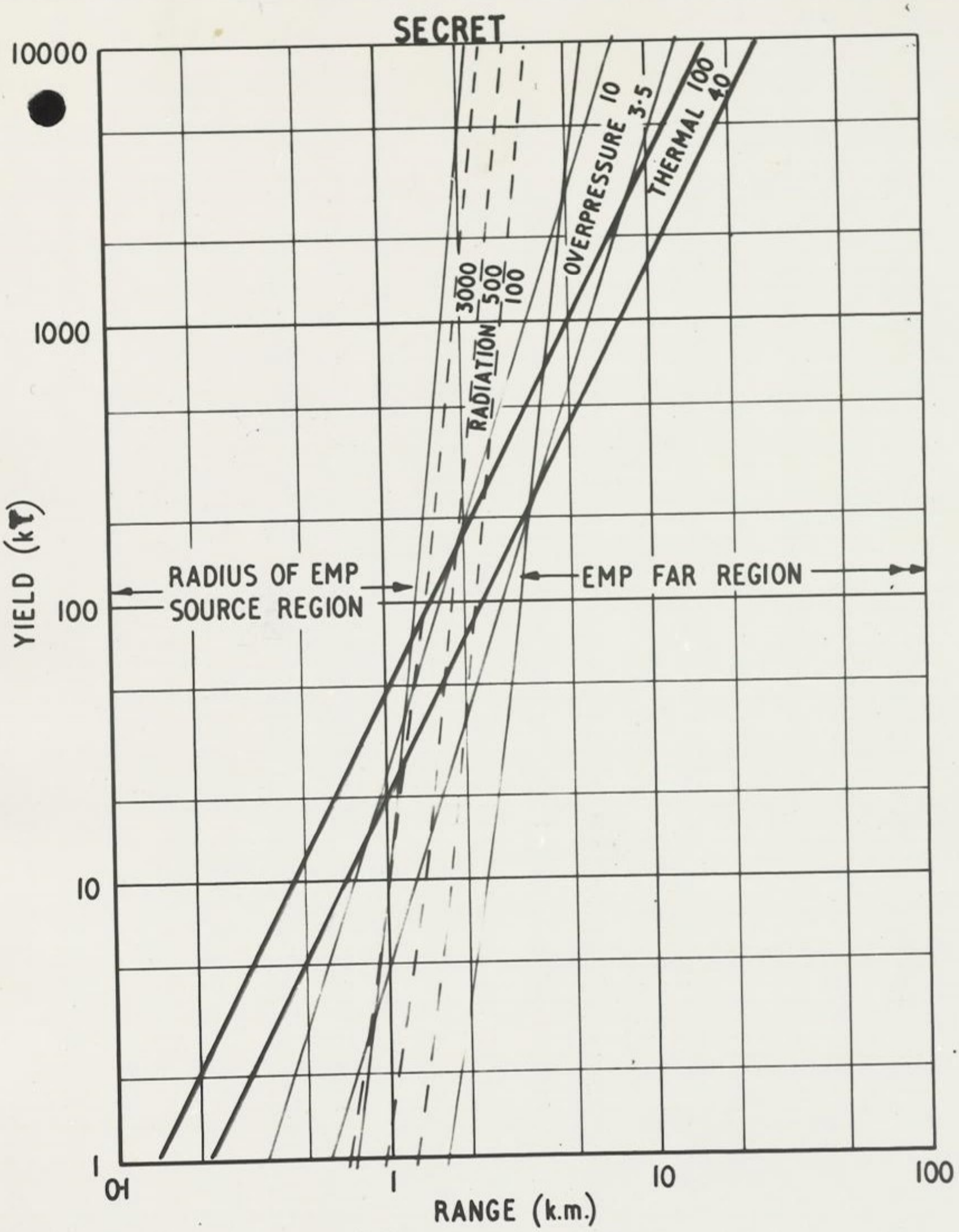
FIGURE 2

SECRET DISCREET



EMP AT 1·5 k.m FROM 250 kT SURFACE BURST

FIGURE 3



EMP REGIONS IN RELATION TO OTHER WEAPON EFFECTS (SURFACE BURST)

FIGURE 4

## PROGRAMME OF WORK

## Design of Naval Superstructures to withstand Nuclear Air Blast

W D Hart (NCRE)

In the Nuclear Blast field NCRE has been concerned in the past few years with the development and proving of the design of lightweight superstructures capable of withstanding 10 psi overpressure from a megaton weapon. The theoretical work at NCRE has been supported by experimental data gained in the various Tripartite HE Blast Trials at DRES Canada. 500 ton TNT blasts have taken place in 1964, 1968 and 1970 and NCRE has participated in all these tests.

If the superstructure of a ship is to be really lightweight and be capable of withstanding 10 psi it is necessary to accept some small plastic deformation. No design can be lightweight and remain within the elastic limit.

The 1964 trial, in which a 2 deck simple box model was exposed, showed that considerable shear buckling in the end bulkhead could occur with only a small movement of the top deck. This observation led to the development of a dynamic design method. The assumptions made are that the loading on decks and bulkheads is modified by the response of the external plating and that their response is modified by buckling and yielding. The method allows calculation of the response beyond the onset of shear wrinkling.

In fact the problem reduces to solving the response of a series of lumped masses interconnected by non-linear springs there being three distinct loading phases -

elastic pre-buckling
elastic post-buckling
plastic post-buckling

Two 1/3rd scale models of a full width superstructure of a destroyer type ship of 4000 tons were designed and built at NCRE, one in steel and one in aluminium. The models were 3 decks high and were of all-welded construction. The models withstood 8 psi in 1968 and 10 psi in 1970 without significant damage. Experimental deflections were slightly less than theoretical predictions, i.e. the method is conservative and provides a safety factor.

Thus a satisfactory design method is available for the design of lightweight superstructures provided that small permanent deflections and shear buckling in bulkheads are acceptable to the overall ship design. The next step is to re-write the design program into a form suitable for use by a design office.

**Another problem that has concerned NCRE is the increased blast resistance of GRP radomes that can be achieved by internal pressurisation. Tests on simple models have been carried out both in the AWRE Blast Simulator and at DRES, where 3 models were exposed in 1970. Results show promise but one of the difficulties is to achieve reproducability in the strength of the GRP skins of the models being tested.**

**ASWE have also been investigating the blast resistance of GRP radomes in particular the Satellite Communication Terminal (SCOT) radome. They likewise have carried out these tests in the Blast Simulator and at Suffield.**

**Future effort will be aimed toward the achievement of an overall balanced design for the blast resistance of ships and to this end improved blast resistance of radomes and aerials is the next step.**

## NATIONAL COMMUNICATIONS AND POWER SUPPLIES

A H Hatton (Cabinet Office)

What I have to say concerns civil telecommunications, including those associated with military requirements, civil broadcasting and electrical power transmission and is no more than a statement of the position we have reached in examining such areas in the general context under review. In the Cabinet Office we are particularly interested in the effect of EMP on those line and radio communications and the supporting electrical power supplies which will be needed to support our Machinery of Government in War planning but we also need to be able to assess the effects of EMP on the general run of telecommunications, for example, the effect of a high altitude burst well removed from the United Kingdom on Post Office telecommunications or a FCO radio station, before any nuclear attack has been mounted directly against the United Kingdom.

Mr Mosley who has now returned from the GSPS to the Ministry of Aviation Supply has prepared a layman's guide on EMP. Some of you will have read it and some of you will have contributed to it. From a reading of this document it is not difficult to visualise how the widespread failure of, for example, Post Office telecommunications could hinder military preparations against attack and demoralise the population as a whole, especially if broadcasting was also affected. At first we felt that we should await the results of the comprehensive investigations being conducted by the Ministry of Defence into the effect of EMP on tactical systems and equipment but we saw advantage in looking at the civil position as a parallel and complementary exercise and it seemed desirable to set up a Working Group for this purpose.

The Working Group is responsible to the Machinery of Government in War Sub-Committee and briefly its terms of reference are:-

1 To review (telecommunication) systems for MGW with reference to those required to work in or be exposed to a nuclear environment.

2 To recommend procedures for the safe storage of equipment and for the hardening of communications.

3 Where necessary to suggest a suitable test programme to confirm the procedures recommended.

4 To maintain liaison with the MOD in order to co-ordinate the information now coming from test programmes of equipment hardening.

The Working Group includes representatives from all those Departments with a major telecommunications interest such as the FCO, Home Office, MOD, MPT, Post Office and the Cabinet Office. The Civil Aviation and Power interests have been brought in at an appropriate stage through MPT. Apart from representing the Ministry of Defence interest in Post Office Communications the MOD representative will also keep the Working Group informed of the tests which are programmed for military purposes and the results. The Working Group is looking to the representatives from the MOD(D Sc) and AWRE, Aldermaston for technical support and advice and this has already been forthcoming in the way of papers on EMP environment and on the design and cost of threat simulators.

So far the Working Group has identified some of the major elements of telecommunications equipment and telecommunications systems which merit investigation for the effects of EMP. They may be divided very roughly into 3 groups:

a Radio equipment for the FCO, Home Office (including Fire and Police), MOD and Post Office.

b Miscellaneous equipment, such as radiation detection devices for the Home Office, and secrecy equipment for the FCO.

c Post Office systems embodying cables and equipment for the use of all Departments.

This last group represents the requirements for wide area communications as opposed to the "black box" requirements of the MOD and will require the development of more refined testing techniques than those being used in the UK at present.

The Working Group has been informed that the threat simulator testing facilities of the AWRE are likely to be fully occupied with military equipment for some years to come and has therefore come to the conclusion that additional facilities are necessary to test civil equipment and systems. Departments have been asked to advise as to what effort in the way of trained staff they could make available to attend simulator tests on their own equipment and to interpret the results and whether they would be prepared to set up a simulator for carrying out tests on behalf of their own and other Departments. Replies on these points are awaited.

A possible alternative is to interest industry in building a simulator for use of Departments on a rental basis and for its own use in meeting EMP acceptance tests likely to be imposed on equipment provided for Government use. It is clear that much of the testing of civil equipment will involve Post Office cable circuits and transmission systems and for this a low level type of simulator embodying some as yet untried techniques will be required.

Some slight contact has been made with the civil authorities in the United States who are interested in EMP but it seems likely that we shall not be able to support a dialogue with them until we have embarked on a programme of tests and have some information to exchange. We believe that other ABCA countries are interested in testing civil communications and that the TTCP Sub-Group N is likely to look at this problem.

Further practical progress cannot be expected until additional testing facilities are available, but advantages can be derived, perhaps, from information arising out of the tests on military equipment which has a general application.

As I said at the beginning this is not more than a brief description of the aims of the Working Group and the thinking which is emerging since we first met in May 1970. Perhaps progress is slow but for most of the members the field is an unfamiliar one and we need to engage as much expertise as is available.

## TRAINING PROGRAMMES

R Rankin (D.sc.6 MOD)

Although this, the last of today's presentations, is entitled 'Training Programmes', I think a more apt term to describe the scope of activities which D Sc 6 sponsors would be 'education'.

The 'education' has to date taken 2 forms. The first to meet the need of providing staff concerned with particular projects with a briefing on the whole field of nuclear weapon effects, and to highlight some of the problems which might arise as a result of these effects on the equipment with which they are concerned. We have so far arranged 3 briefings of this type, for MRCA, MALLARD and CLANSMAN; all 3 have been of one days duration, and needless to say, only a broad brush treatment is possible in this time.

Where we have considered a more detailed instructional approach is necessary is in the case of transient radiation and electromagnetic pulse effects on electronics. In the case of transient radiation effects, the designers of circuitry are faced with what are to them unfamiliar problems, and education is necessary, particularly in the application of analytical techniques. Closely linked with the TREE problem is that arising from EMP effects on circuits; the designer is faced with the problem that, within the same time frame in which photocurrents are induced by transient radiation, further currents may enter the system by various pick-up modes from the electromagnetic signal. To acquaint designers with the problems and possible solutions, AWRE have instituted courses of one weeks duration. The course comprises a general introduction on nuclear weapon effects, sessions on the effects of nuclear radiation on semiconductor materials and circuits and methods of counteracting these effects, the effects of EMP and circumvention techniques, and visits to the simulation facilities at AWRE. The first of these courses was held in September for personnel from firms involved in the then Project MALLARD. The next courses, starting on Monday, will be for the staff of the Army Department R & D establishments.

In view of the amount of design work on service electronics now carried out by industry, we hope that future courses will largely be attended by designers from industry, although of course we welcome attendees from the R & D establishments. With the aid of these courses we hope to establish, within a year or 2, sufficient expertise to be able to cope with most of the problems of hardening which may arise.

As I have said, we have placed the emphasis on transient radiation and EMP effects on electronics. Should anyone experience problems in any other areas of nuclear weapon effects, we will be only too pleased in D Sc 6 to discuss these problems with them and to assist in any way possible.

# ATTENDANCE AND DISTRIBUTION LIST

## A

| | |
|---|---|
| ✓ Maj K E P Andrews | SIGS 31 (ARMY) |
| ✓ Mr J D Armstrong | HEL Ampthill |
| ✓ Gp Capt G J Aylett | A & AEE |
| ✓ Mr P J Atkins | AWRE |
| ✓ Lt Col T W Armour | AWRE/ARMY |
| ✓ Wg Cdr A Andrews | OR 31 |

## B

| | |
|---|---|
| ✓ Mr E Benn | DPS |
| ✓ Maj B Burke | AWRE/ARMY |
| ✓ Dr C G Bradshaw | Project MALLARD MAS |
| ✓ Lt Col P H Budden | GS(OR)4 |
| Mr Brook | D Sc 1/7 |
| ✓ Mr J H Bagley | SRDE (Cabinet Office) |
| ✓ Dr R Batchelor | AWRE |
| ✓ Mr C E Byatt | A & AEE |
| ✓ Wg Cdr D G Beal | AWRE/RAF |
| Lt M M S Brown | DI 57 |
| ✓ Lt Cmdr M A Broomfield | ASWE |
| ✓ Mr R S Burns | RARDE |
| ✓ DR. BULSON | MUEE. |
| ✓ MR BOSWELL | MVEE |
| ✓ J.R. BAKER | GS(OR)2. |

## C

| | |
|---|---|
| ✓ Col A A V Cockle | RAC Centre Bovington |
| ✓ Mr R E L Cleaver | CS(Energy) DIV |
| ✓ Col W G R Corkill | GS(OR)6a |
| ✓ Maj D J R Counsell | GS(OR)14 |
| ✓ Mr H W Cross | RRE Malvern |
| ✓ Mr F A Cunnell | RRE Malvern |
| ✓ Mr P F Cook | Air Reg Board |
| ✓ Mr J D Culshaw | DCSO - Home Office |
| ✓ Mr J F Coates | DG Ships (N) |
| ✓ Mr D J Collyer | AWRE |
| Mr F J Chesterman | DNPR |
| Mr A E Clark | H/NP |
| ✓ Mr P Crellin | A Arm 3 |
| ✓ Maj Cox | School of Artillery |

## D

| | |
|---|---|
| ✓ Mr D Delaney | ASWE |
| ✓ Sq Ldr D E Dormer | MRCA/L |
| ✓ Mr E Draper | D of Safety (AD) |
| ✓ Mr J D Davies | AWRE |
| ✓ Air Cdre S M Davidson | D Sigs (AIR) |

## E

| | |
|---|---|
| ✓ Lt Col V Edwards | Sigs 40(A) |
| ✓ Mr J Ellis | MVEE |
| ✓ Cdr L E Elwell | AWRE/RN |
| ✓ Lt Col N W J England | AMD 7 |
| ✓ Mr H D Evans | RGA Civil Defence |
| ✓ Air Cdre Eyre | D A Arm |

### F

| | |
|---|---|
| ✓Col M J R Fletcher | DSS |
| ✓Cdr J M Findlay, RN | DNS |
| ✓Mr R D S Foxwell | HEL Ampthill |
| ✓Mr R F Fordham | UKAEA |
| ✓Col K A Foster | DGFVE |
| ✓Gp Capt S E Fawson | Ordnance Board (N-Div) |
| ✓Mr R A Fothergill | AWRE |
| ✓Sq Ldr J F Fincher | OR 30d |
| ✓Maj N H Fletcher | GS(OR)17 |
| Wg Cdr Ferenczy | Sigs AIR |
| Mr R S Freeman | MAS GW |

### G

| | |
|---|---|
| ✓Brig C D Gardiner | Cabinet Office |
| ✓Dr E M Gunnerson | AWRE |
| ✓Maj L P J Gatfield | DI 52 |
| ✓Lt Col P F W Gahan | DSS |
| ✓Col R H Gilbertson | DSS |
| ✓Mr A Grimes | CS (ARMY) |
| ✓Mr D J Garrard | TLI |
| ✓Mr H Gaunt | RRE Malvern |
| ✓Mr T Griffiths | D of TI |
| ✓Lt Col A B Good | DGFUE |
| ✓Cdr A W Griggs | DI 57 |
| ✓Mr H George | D of TI (CPPI) |
| ✓Mr A D Greenhalgh | AWRE |
| Mr P L W Gibbons | RAE |
| ✓SQN. LDR. S.E. GOWING. | D.I.52. |

### H

| | |
|---|---|
| ✓Mr G F Hocking | A & AEE |
| ✓Mr J Highcock | D Sc 8 |
| ✓Sq Ldr G M Hitchings | Sigs 50 (AIR) |
| ✓Mr A J Hitchcock | AWRE |
| ✓Mr R D Holland | DWRDS(N) |
| ✓Surg Cdr C O Hughes | CNNSTP |
| ✓Surg Capt J M Hanson | MDG(N) |
| ✓Mr W D Hart | NCR EST |
| ✓Mr G Hicks | RAE |
| ✓Mr F A Hough | Post Office |
| ✓Lt Col W F D Hawkins | Post Office |
| ✓Mr A H Hatton | Cabinet Office |
| ✓Mr R F Hill | SRDE |
| ✓Col J N Hallett | Project Man.(CLANSMAN) |
| ✓Wg Cdr R G M Hubbard | NBC School |
| ✓Maj A J D Hughes | NBC School |
| ✓Mr G Haugh | Science 2(RAF) |
| Maj T Hackworth | AWRE/ARMY |
| ✓RR. ADM. HIGHAM. | ACNS(OR) |

### I

| | |
|---|---|
| ✓Mr J K A Ives | MVEE |

## J

| | |
|---|---|
| ✓ Lt Cdr Parker-Jervis | DNBCS |
| ✓ Mr W R Joy | DNPR |
| ✓ Mr E T Jones | SRDE |
| ✓ Mr E W Jackson | SI of NUC INST |
| ✓ Mr W M Jarvis | D Sc 2 |
| ✓ Mr D James | D Sc 6 |

## L

| | |
|---|---|
| Mr T Leggett | HQ OAD NO 1 BR Corps |
| ✓ Lt Col E M Lock | RRE Malvern |
| ✓ Col C A Landale | RSME Chatham |
| Mr Lorimer | D Sc 7 |
| ✓ Mr W A Lemmer | D Sc 1/7 |
| ✓ Lt Col J M N Lyons | Sigs 35 (ARMY) |
| ✓ Lt Col D R H Longfield | MGO SEC 3 |
| ✓ Mr L N Large | DCVD |
| ✓ Wg Cdr Lindsay | INM Alverstoke |
| ✓ Mr W B H Lord | DCS (A) |
| ✓ Maj C J Lewthwaite | AMD 5 |
| ✓ Mr J E D Lakin | Cabinet Office |
| ✓ Dr J F Loutitt | MRC |

## M

| | |
|---|---|
| ✓ Mr G W A Morris | D Sc 10 |
| ✓ Mr D S G Mullins | ASWE |
| ✓ Mr J D R McQuillin | RRE Malvern |
| ✓ Air Cdre G M McMinn | DLRD(A) |
| Sq Ldr E L McMullen | GS(OR)4 |
| ✓ Mr J F McCulloch | DWRDS (ASWE) |
| ✓ Mr G Miller | DoTI |
| ✓ Mr M H McTaggart | AWRE |
| ✓ Capt W Morris | DRNAH |
| ✓ Brig V M Metcalfe | DDEME(A) |
| ✓ Mr R Meakin | RARDE |
| ✓ Mr A D McCree | RARDE |

## N

| | |
|---|---|
| ✓ Maj J H T Nealon | School of Signals |
| ✓ Mr D Noel | RAE |
| ✓ Mr K G Norman | AWRE |
| ✓ Mr T Nicholson | DD Sigs 2(AIR) |

## O

| | |
|---|---|
| ✓ Mr T K Overton | SGRDE |
| ✓ Mr S H Oelman | MVEE |
| ✓ Mr W L Oliver | RAE |

## P

| | |
|---|---|
| ✓Mr L R Palmer | D A Arm |
| ✓Dr F H Panton | ACSA(N) |
| ✓Lt Col R G Phippard | Sigs 35c |
| ✓Capt P C Prince | D NS |
| ✓Dr W H Penley | CS Army |
| ✓Mr R Poland | RAE |
| ✓Mr E S Parkes | CESG |
| ✓Mr P A M Perry | RAE |
| ✓Mr W T S Pearson | RAE |
| ✓Mr A D Perryman | SAB Home Office |
| ✓Mr F H Pavry | SAB Home Office |
| ✓Mr T S Popham | Ordnance Board |
| ✓Brig J I Purser | DOR1(A) |
| ✓Lt Col R I D F Painter | School of Sigs |
| ✓Wg Cdr J F Potter | OR30(RAF) |
| Mr P E H Pearce | DNPR |
| Mr G Price | MAS/EQD |
| ✓MR. PULLEYN | MVEE. |
| ✓MR. T. H. PRATT. | D. Sc. 14 |

## R

| | |
|---|---|
| ✓Mr D P R Roessler | D Sc 2 |
| Maj R I Radford | GS(OR)7 |
| ✓Mr I M Ross | CS(A)Sec 3 |
| ✓Dr H Roberts | H/NP |
| ✓Mr P H Reed | RAE |
| ✓Dr J M Rodgers | RRE Malvern |
| ✓Mr L D G Richings | Rad Prot Board |
| ✓Mr G F I Roberts | Gas Council |
| ✓Mr R Rankin | D Sc 6 |
| ✓Mr C Redmayne | AD/MRCA |
| Mr D G Robertson | HQ STC |
| ✓MR. D. A. L. ROBSON. | M.A.S. |

## S

| | |
|---|---|
| ✓Mr D E J Samuels | AWRE |
| Capt R W Stark | School of Sigs |
| Dr K Stewart | AWRE |
| ✓Mr W H Sellek | AWRE |
| ✓Maj R Samuelson | GS(OR)5 |
| ✓Dr I J Shaw | D Sc 1/7 |
| ✓Mr W N Saxby | D Sc 6 |
| ✓Maj V S Smith | Sigs 1 (ARMY) |
| ✓Dr B W Soole | ARL Teddington |
| ✓Mr G S S Speak | DA Arm (MAS) |
| ✓Mr K F Slater | DLRD(A) |
| ✓Lt Cmdr M A G Simpson | DI 57 |
| ✓Cdr J D Steele RN | DNOR |
| ✓Mr W A Sutherland | RARDE |
| ✓Mr R W Storey | Min of Posts and Telecoms |
| ✓WG. CDR. D. STURROCK | DHR. FARNBORO. |
| ✓MAJ. SAUL. | SIGS. 36. |

## T

| | |
|---|---|
| ✓Mr C K Thornhill | RARDE |
| ✓Mr S D Taylor | DWRDU(N) |
| ✓Mr L J A Theobald | RDI FIRES |
| Mr H L Troughton | DD/MVEE |
| ✓Mr F J H Tutt | MVEE |
| ✓Mr D J Thomas | RMCS Shrivenham |
| Lt Cmdr R A Thompson | DNS |

### V

| | |
|---|---|
| ✓ Mr P D Verschoyle | CS(A) Sec 1 |
| ✓ Lt Col D R L Vaudrey | AWRE/ARMY |
| MR. I. VARNHAM. | ARMY |

### W

| | |
|---|---|
| ✓ Gp Capt J B Wellingham | DSS |
| ✓ Lt Col D R Whitaker | RMCS Shrivenham |
| ✓ Gp Capt S C Rexford-Welch | AWRE/RAF |
| ✓ Mr P W Williamson | AWRE |
| ✓ Mr A Walker | D Sc 5 |
| ✓ Mr H S Weeks | DI 52 |
| ✓ Lt Col D W B Williams | AWRE/ARMY |
| ✓ Mr J H Williams | CNR |
| ✓ Dr Wyatt | RAE |
| ✓ Mr H E Walker | DWRDS(N) (ASWE) |
| ✓ Dr G Woolridge | DGW(A) |

### Y

| | |
|---|---|
| ✓ Mr E W F Yirrell | Home Office |
| ✓ MAJ. YOUNG. | P.M. CLANSMAN. |

NOTES.

C.N° 4 SENT TO DUS(E).
" " 7 " " D.A. NAV – MR. J. GATE. 3/12/71.
" " 21, 22, 23, 25, 29, 30, 71, 84, 88, 89 } " " COL. P.H. BUDDEN GS(OR)4. – 21/4/71.
" " 93, 98, 99 } " " T.R.C ST. MARY CRAY – 11/5/71
" " 105 " " DCDA – COL. P.T.G. BATES 12/5/71
" " 107, 110 } " " NSTIC · STATION SQ HSE ST. MARY CRAY. 21/5/71.
" " 111 " " GWM4 – MR. DAWLING. –
" " 115 " " GP. CAPT HELLAWELL. –
" " 116 " " GP. CAPT BANSTONE – RAF GERMANY. –
" " 117 " " MR. E. DEARDEN – AWD. –
" " 118 " " MRS. M.G. GARRARD – GW(G+C) 3. –
" " 119 " " MR. P.G. PRICE (EQD/AW) MOAS WOOLWICH.
" " 120 " " MR. A.R. PEACOCK – NAV 1(b). ST. GILES.
" " 121 " " MR. J.R. TURNER – T.I.O. RARDE.

C.N°. 122 SENT TO MISS MALINS – LIBRARIAN MARCONI.
" 123, 124 } " " MR. B.E. BAKER – HQ STC.
" 130 " " MR. J.H. WILLIAMS – C.N.R.
" 131 " " MR. P.A.M. PERRY – RAE FARNBORO. 14/3/72
" 141 " " MR. D. GARRARD – P/MALLARD 1/10/71.
" 147 " " CAPT. ROBERTSON – BATH 22/3/72.